US009345109B2

(12) **United States Patent**
Briggs

(10) **Patent No.: US 9,345,109 B2**
(45) **Date of Patent: *May 17, 2016**

(54) **LIGHTING APPARATUS AND METHODS FOR CONTROLLING LIGHTING APPARATUS USING AMBIENT LIGHT LEVELS**

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(73) Assignee: **ARKALUMEN INC.**, Ottawa (CA)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/606,012**

(22) Filed: **Jan. 26, 2015**

(65) **Prior Publication Data**

US 2015/0245446 A1 Aug. 27, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/423,135, filed on Mar. 16, 2012, now Pat. No. 8,941,308.

(60) Provisional application No. 61/453,542, filed on Mar. 16, 2011.

(51) **Int. Cl.**
H05B 37/02 (2006.01)
H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 37/0218*** (2013.01); ***H05B 33/0818*** (2013.01); ***H05B 33/0842*** (2013.01); ***H05B 33/0854*** (2013.01); *H05B 37/0272* (2013.01); *Y02B 20/46* (2013.01)

(58) **Field of Classification Search**
CPC H05B 33/0869; H05B 33/0872; H05B 33/0863; H05B 37/0218; H05B 37/0272; F21V 23/0442; F21V 9/10; F21V 23/0457; G09G 2360/144; G09G 2320/0633; G09G 2370/16; G09G 2380/06
See application file for complete search history.

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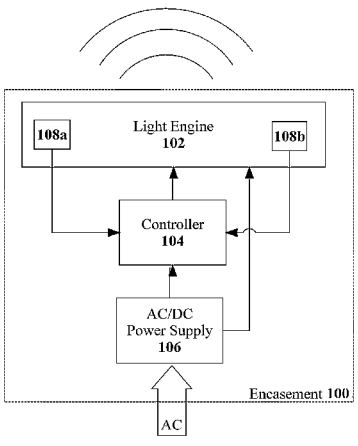
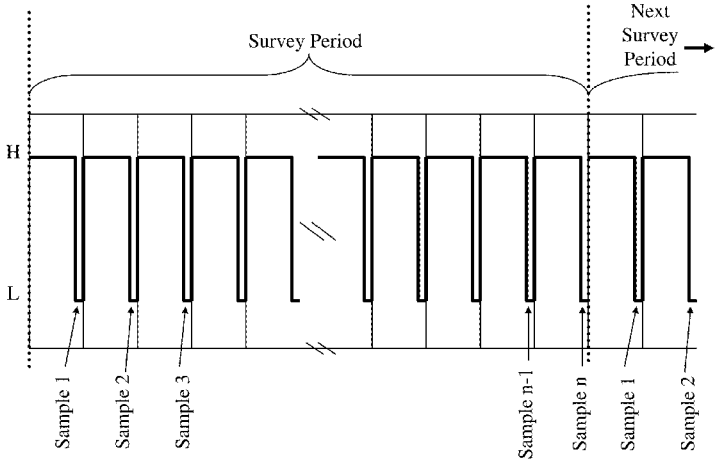
Primary Examiner — Vibol Tan
(74) *Attorney, Agent, or Firm* — Murray IP Consulting Inc.; Sean Murray

(57) **ABSTRACT**

The present invention is directed to lighting apparatus and methods for controlling lighting apparatus using ambient light levels. A controller within a lighting apparatus is used to activate and deactivate one or more light radiating devices within a duty cycle. In a first stage, the controller uses a light detection apparatus to sample the ambient light level at a plurality of sampling times during which the light radiating devices are deactivated. The light level when the light radiating devices are deactivated is an indication of the ambient light levels within the surrounding area of the lighting apparatus. The sampling times occur in different duty cycles within a survey time period. The controller determines an average for the light levels sampled over the survey time period, thus generating an averaged ambient light level over the survey time period. In a second stage, the controller adjusts an intensity of the light radiating devices based at least partially upon the averaged ambient light level. The controller may generate a target light level using the averaged ambient light level over the survey time period and a desired light level and, over an adjustment time period, incrementally adjust the intensity of the light radiating devices towards the target light level.

20 Claims, 18 Drawing Sheets





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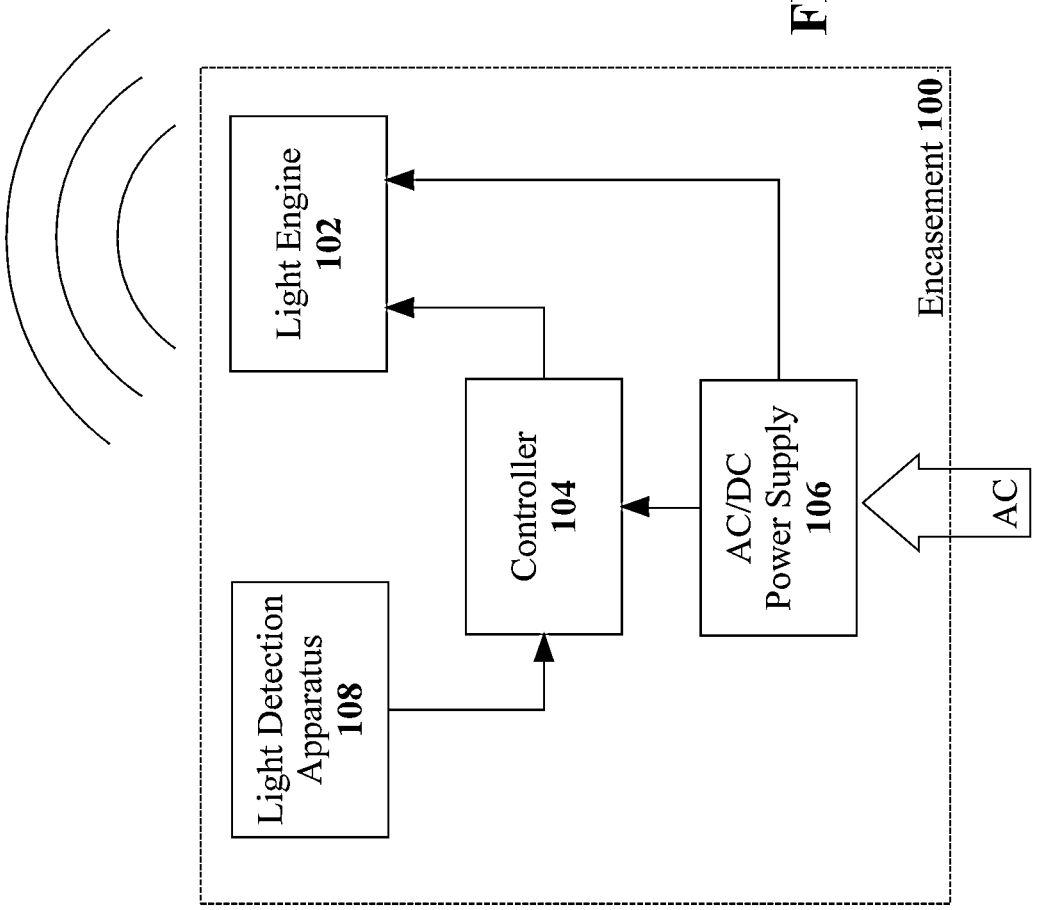
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Controller 104
AC/DC Power Supply 106
AC
Light Detection Apparatus 108

FIGURE 1A

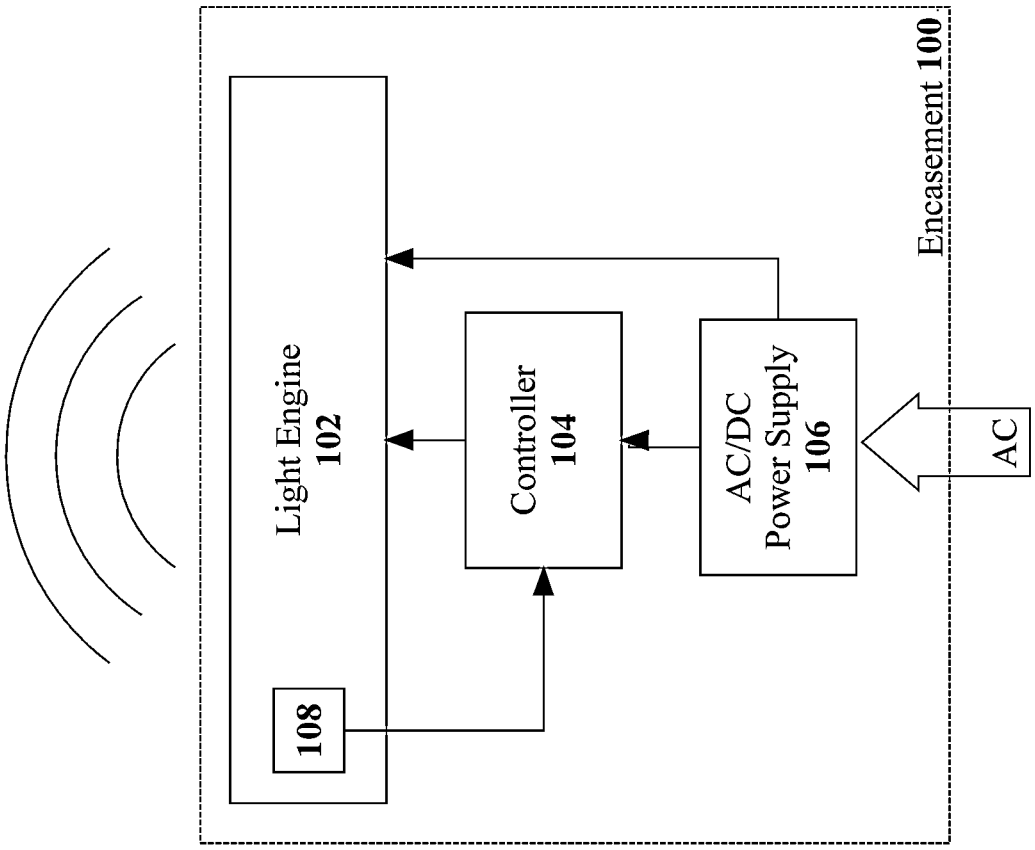
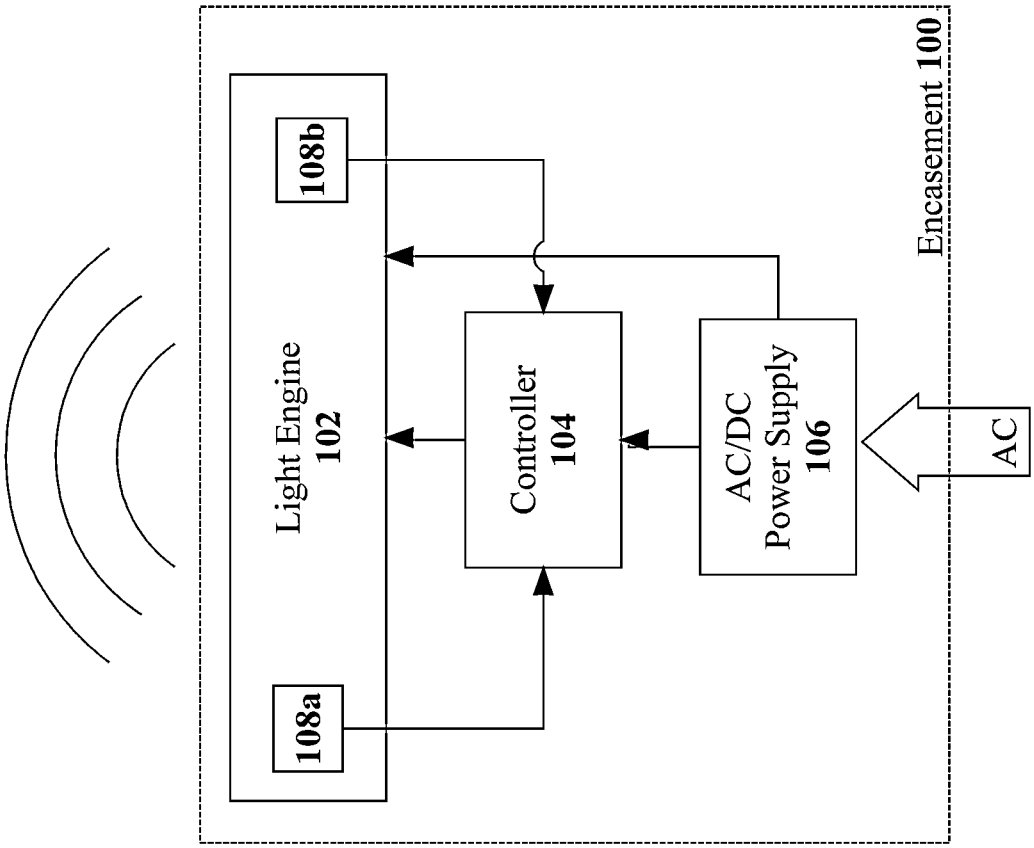
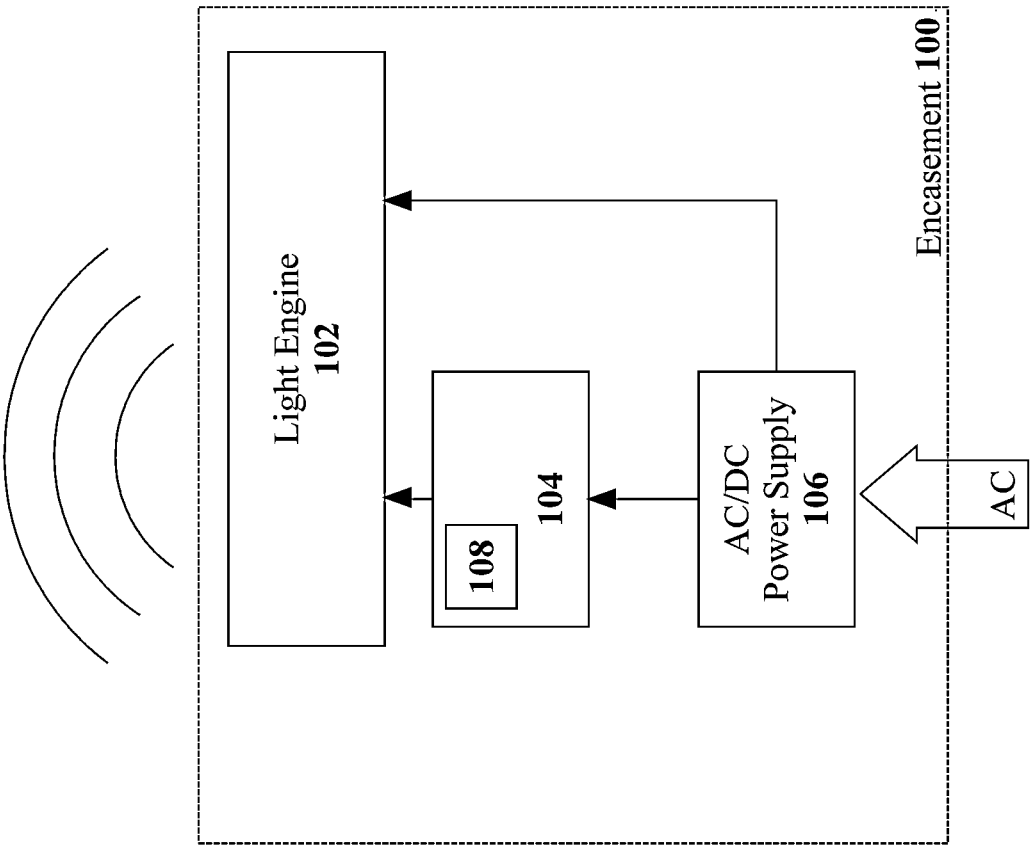

Encasement 100
Light Engine
102
108
Controller
104
AC/DC
Power Supply
106
AC

FIGURE 1B

FIGURE 1C


Encasement 100
Light Engine 102
108b
108a
Controller 104
AC/DC Power Supply 106
AC


Encasement 100
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102
104
108
AC/DC
Power Supply
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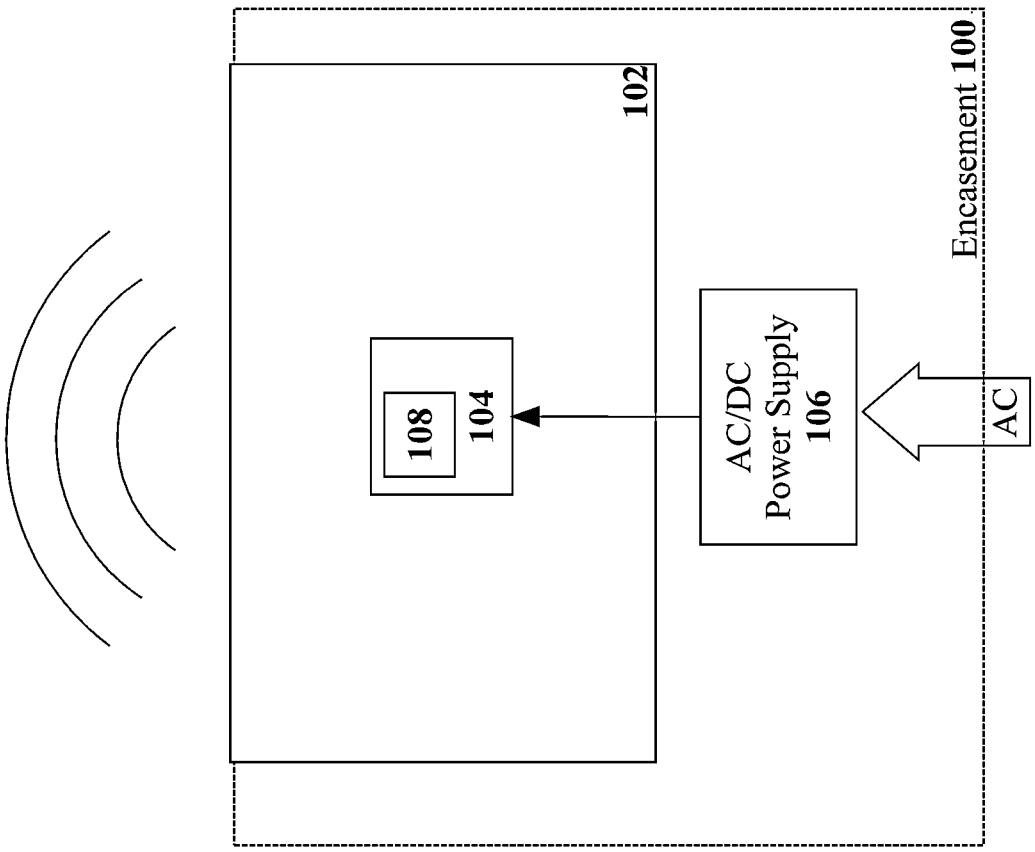
AC

FIGURE 1D

FIGURE 1E



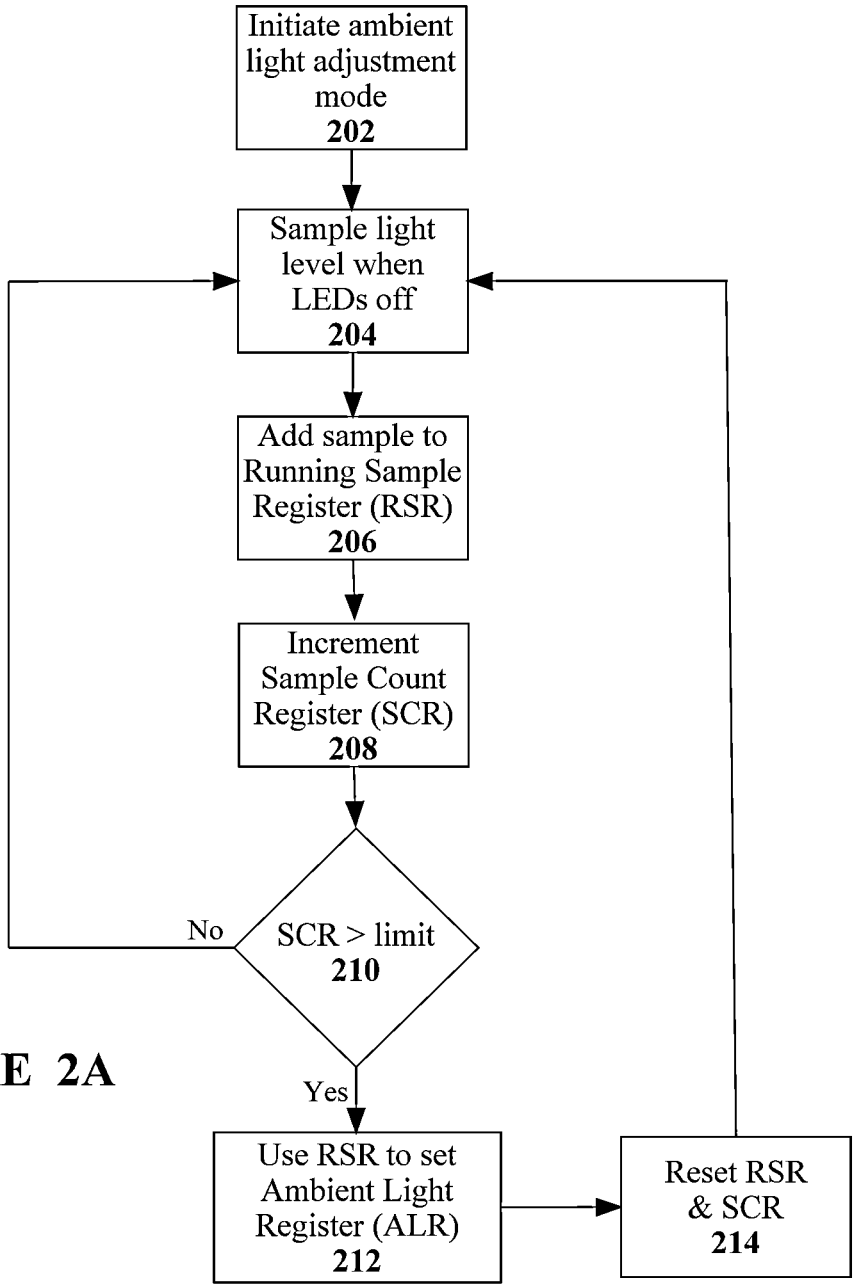

Initiate ambient light adjustment mode
202
Sample light level when LEDs off
204
Add sample to Running Sample Register (RSR)
206
Increment Sample Count Register (SCR)
208
SCR > limit
210
No
Yes
Use RSR to set Ambient Light Register (ALR)
212
Reset RSR & SCR
214

FIGURE 2A

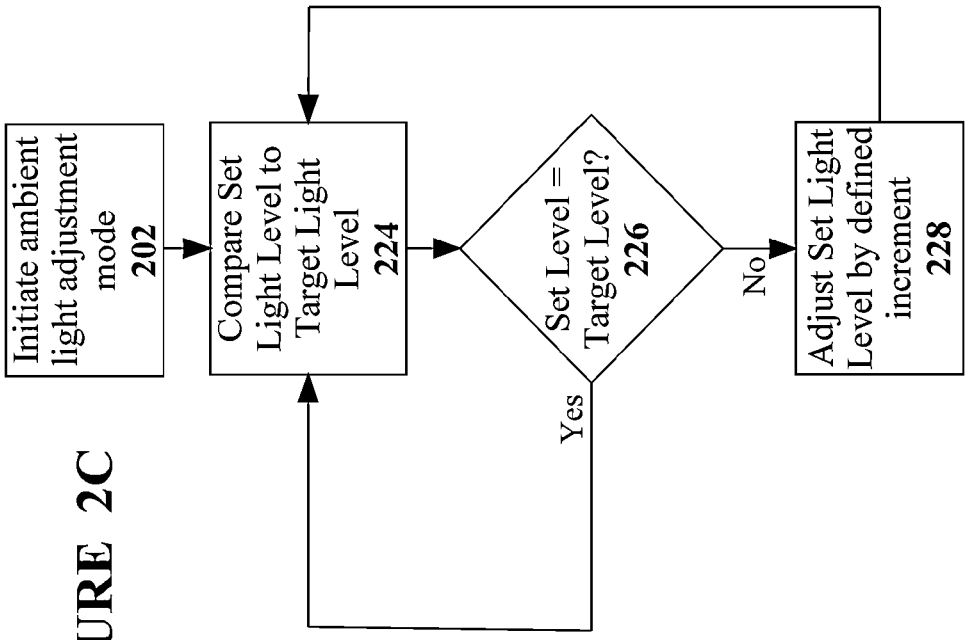
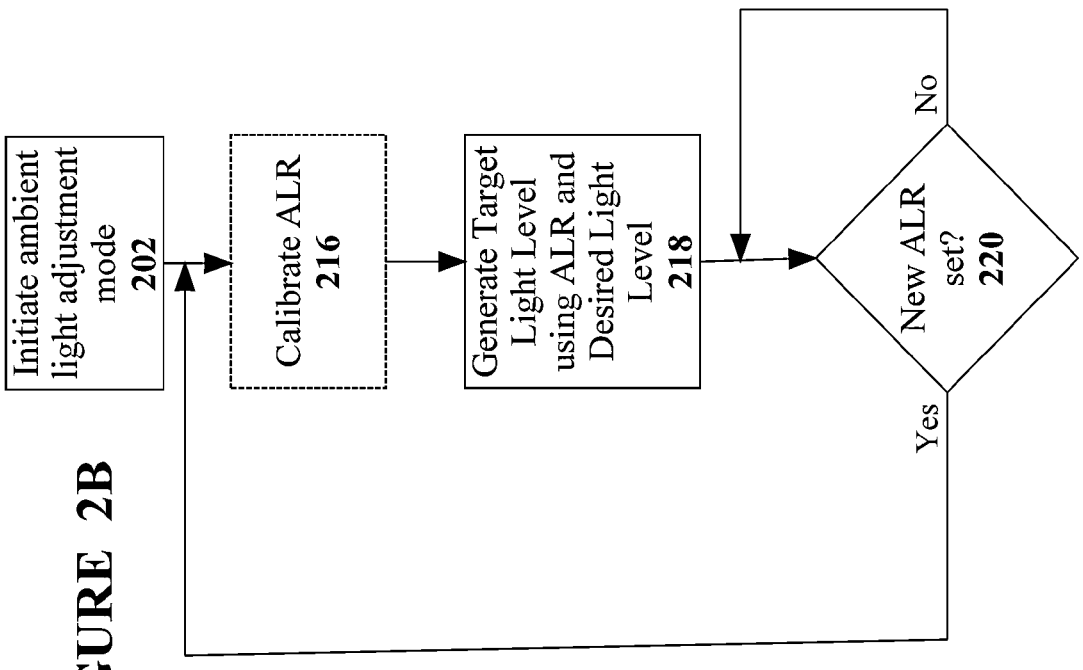


FIGURE 2C



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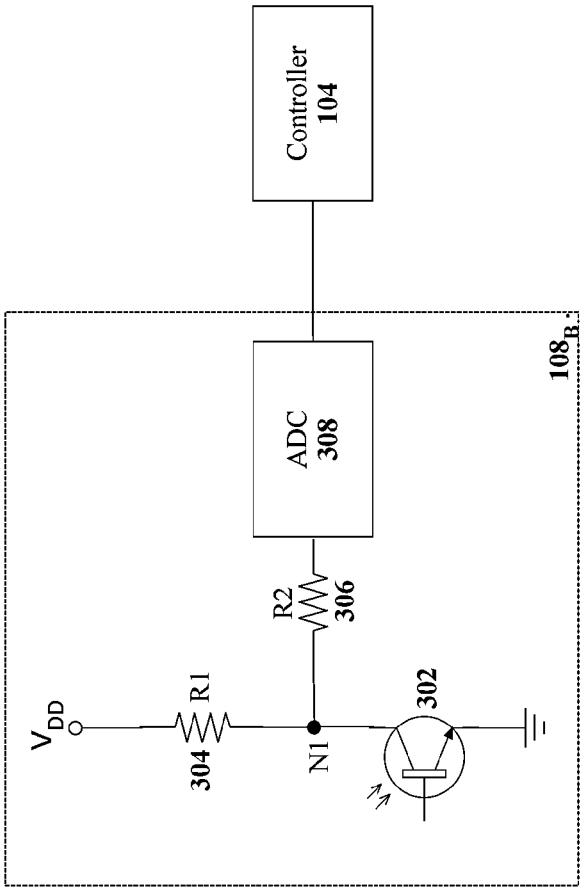

FIGURE 3B

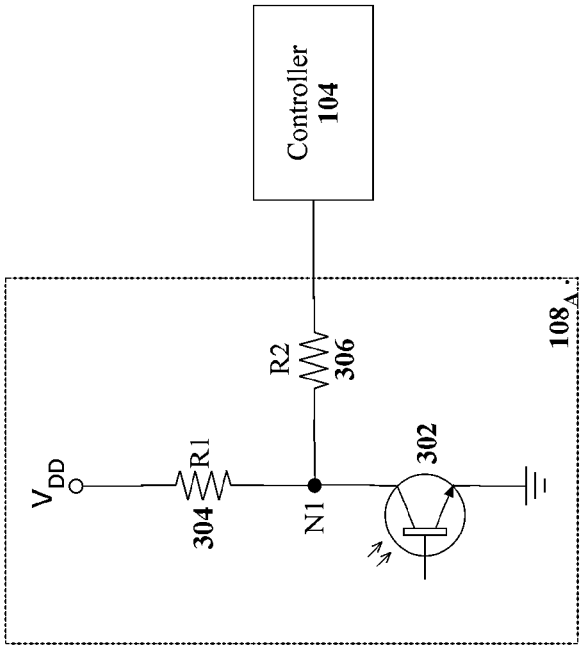

FIGURE 3A

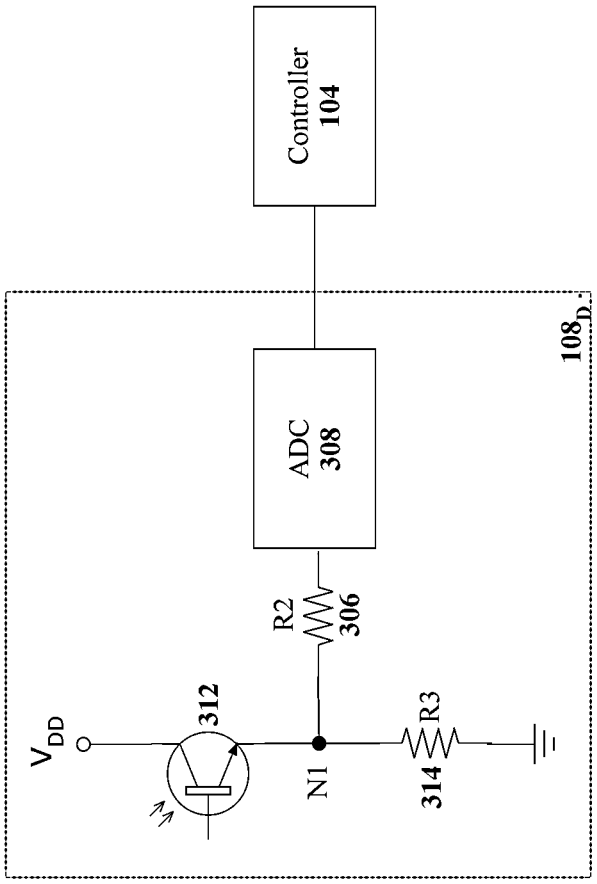

FIGURE 3D

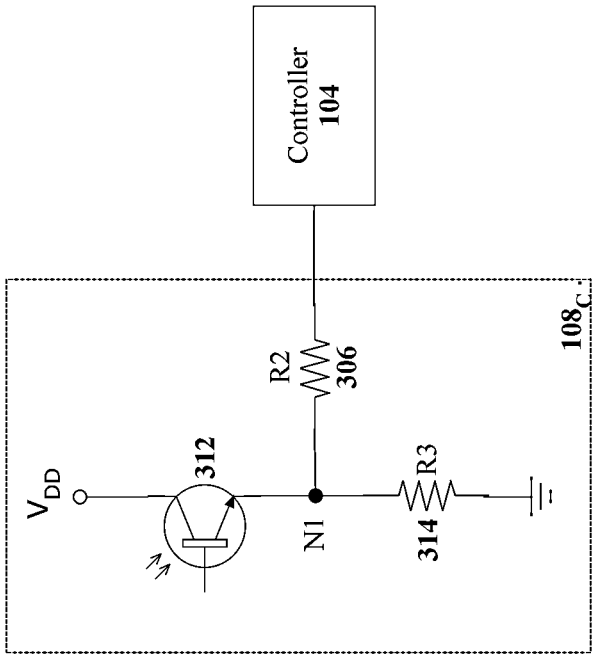

FIGURE 3C

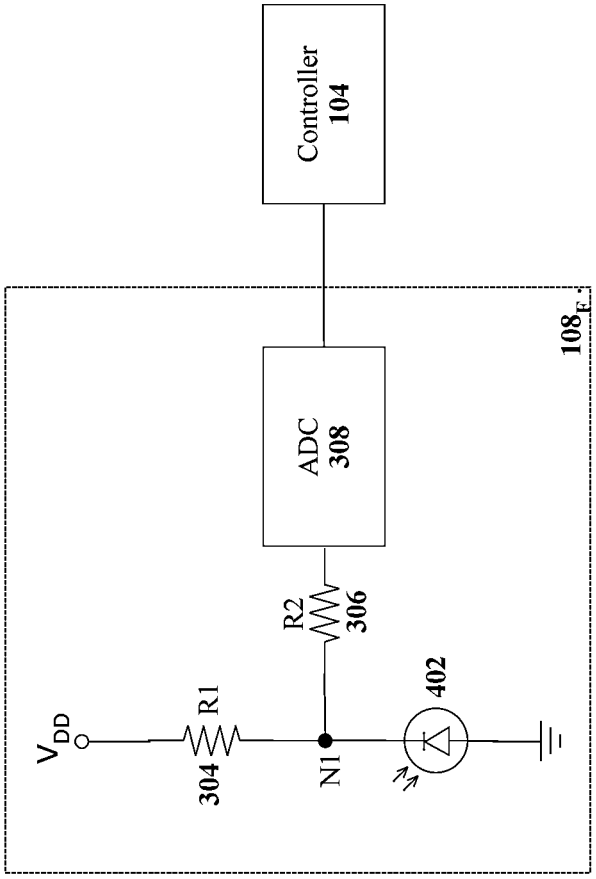

FIGURE 4B

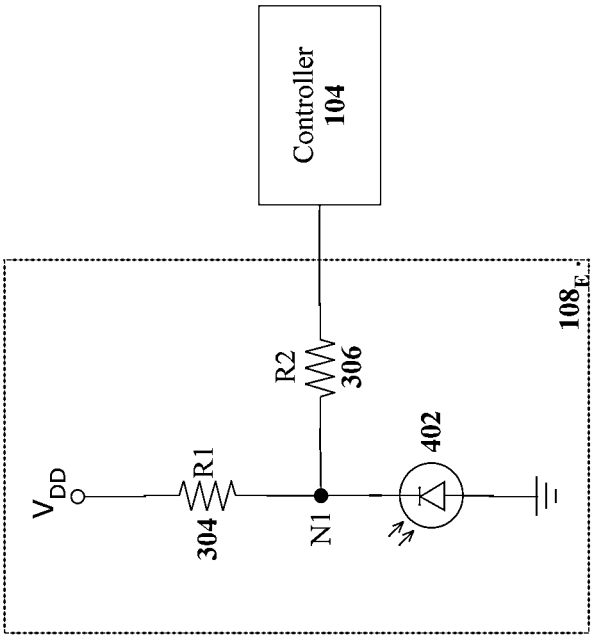

FIGURE 4A

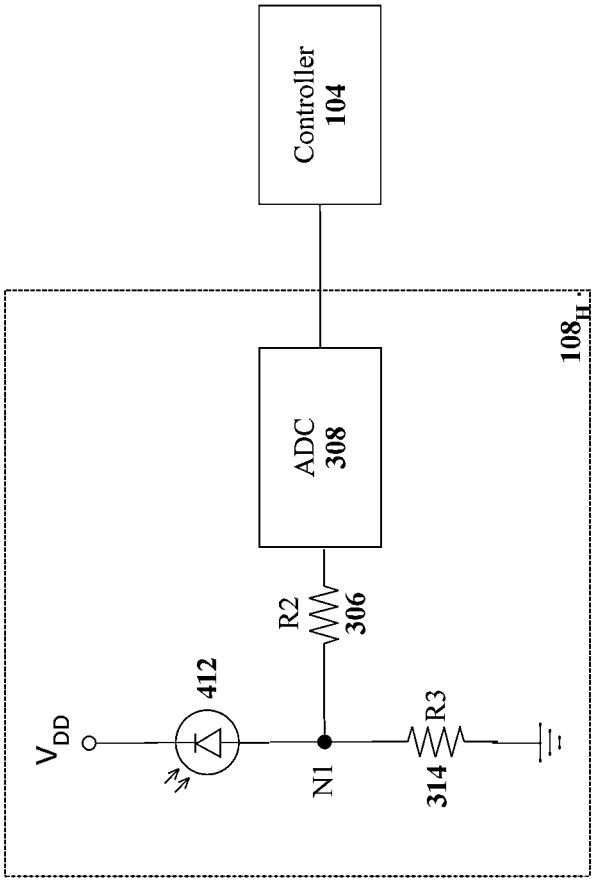

FIGURE 4D

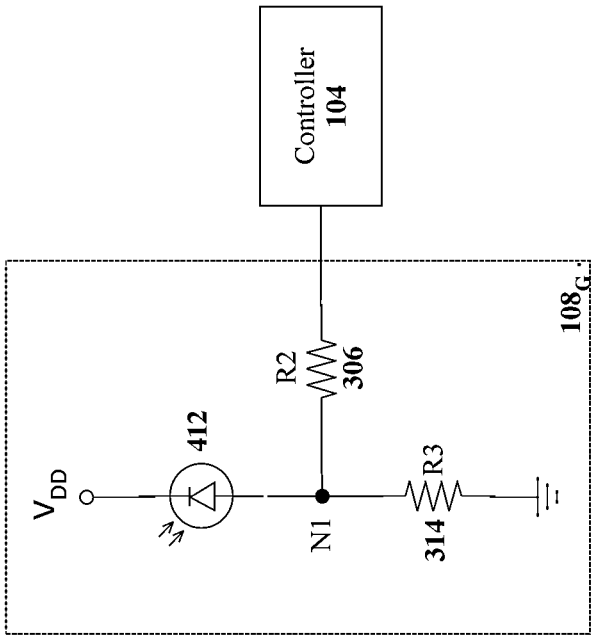

FIGURE 4C

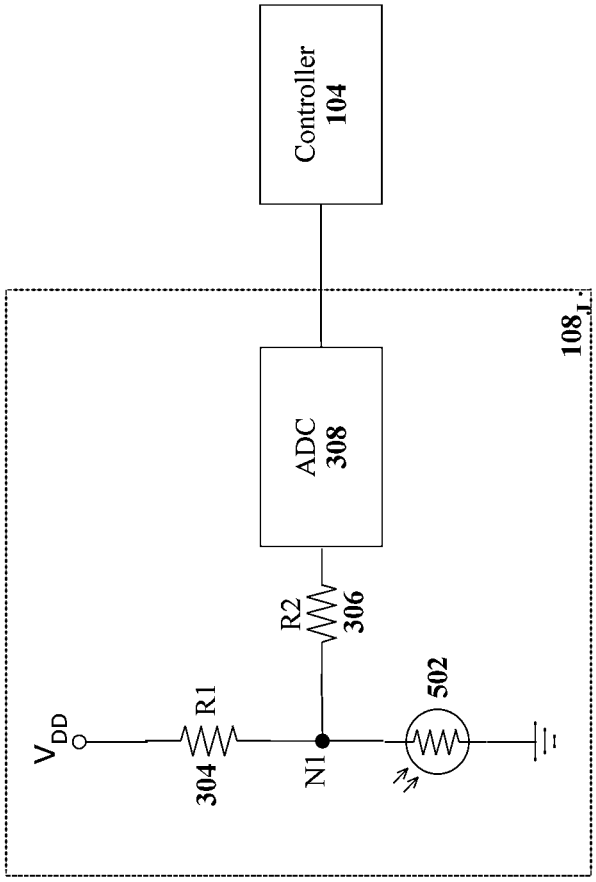

FIGURE 5B

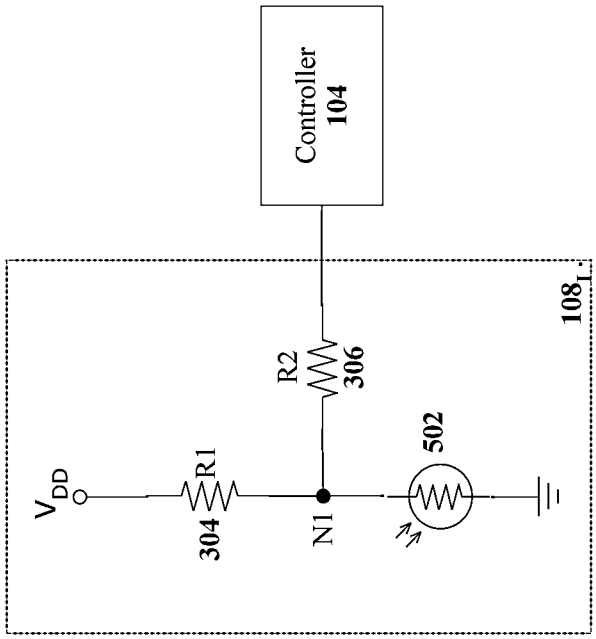

FIGURE 5A

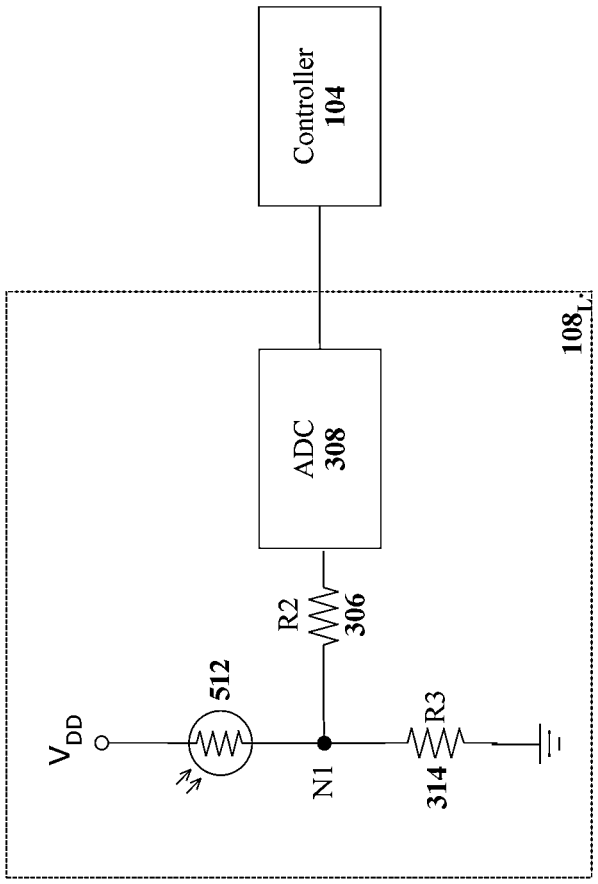

FIGURE 5D

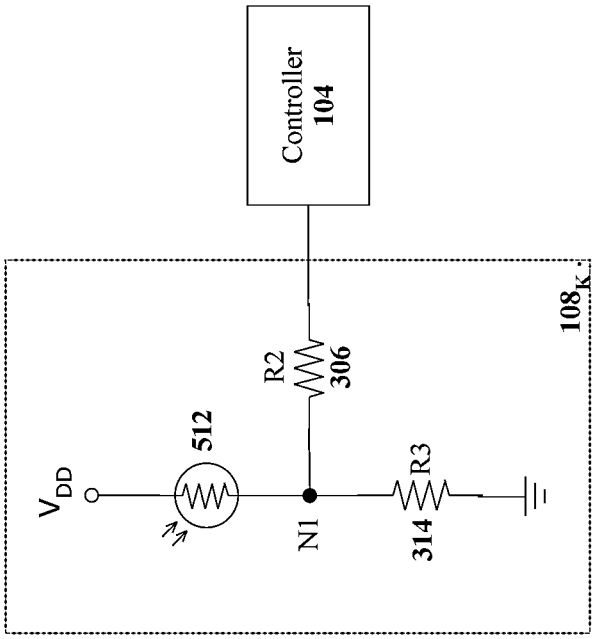

FIGURE 5C

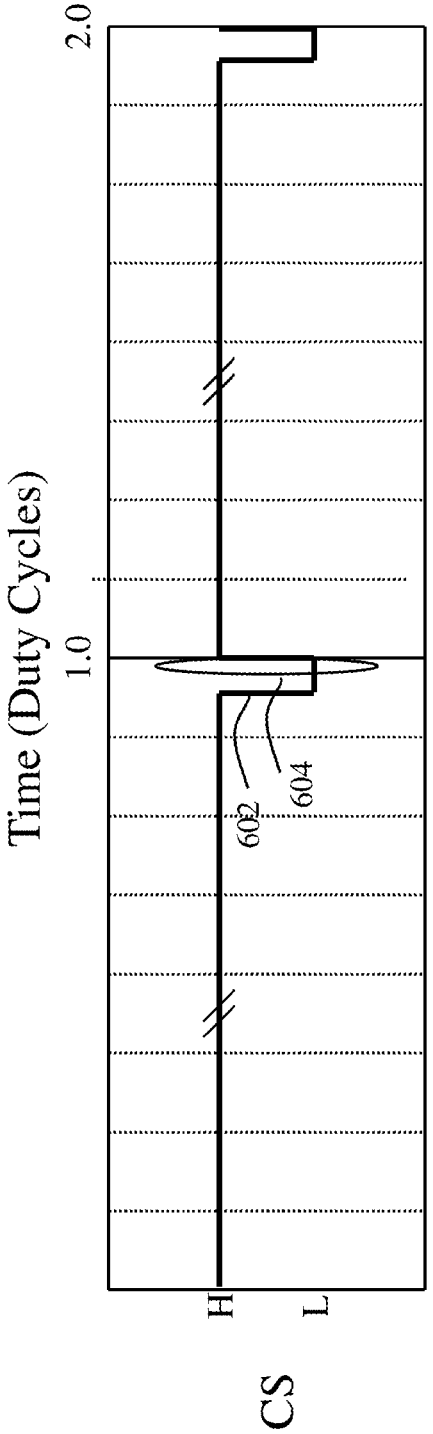

FIGURE 6A

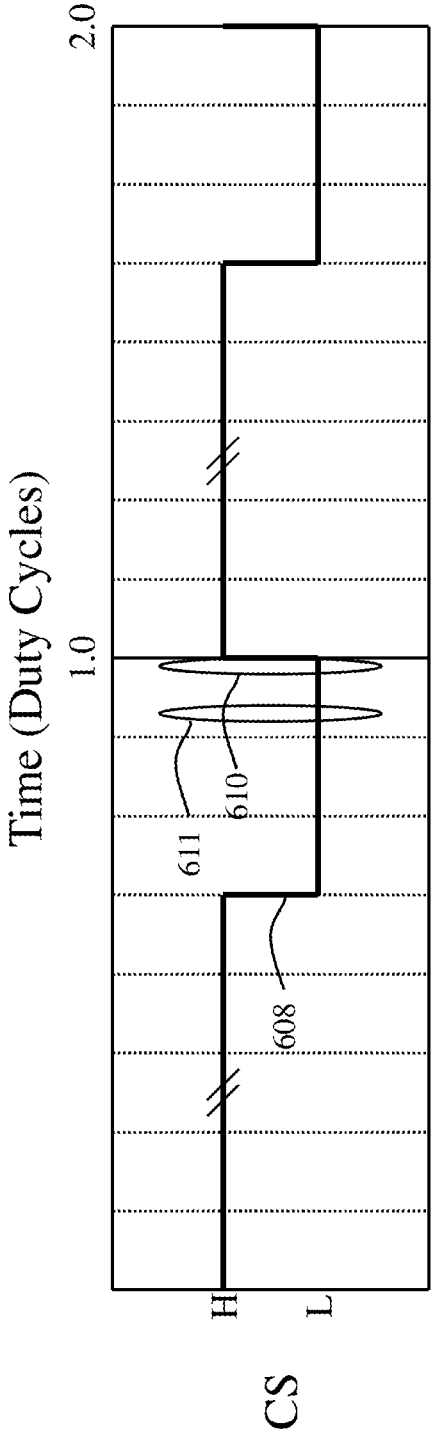

FIGURE 6B

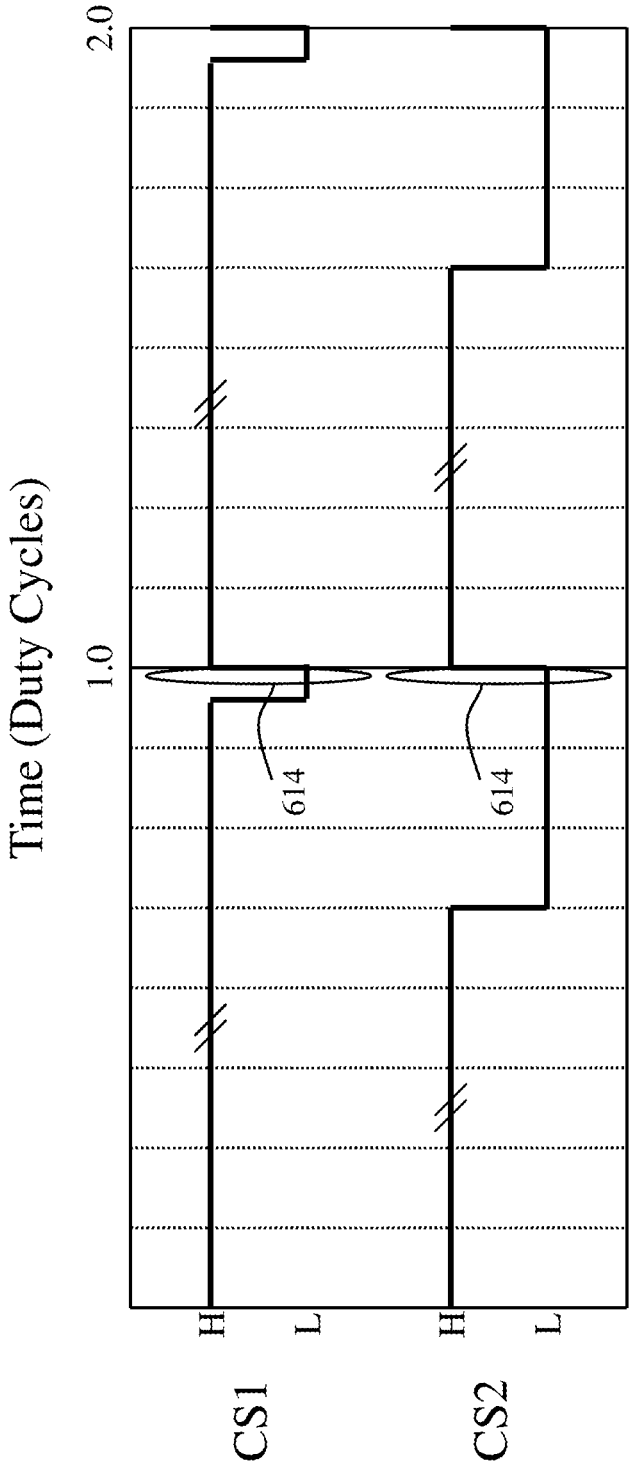

FIGURE 6C

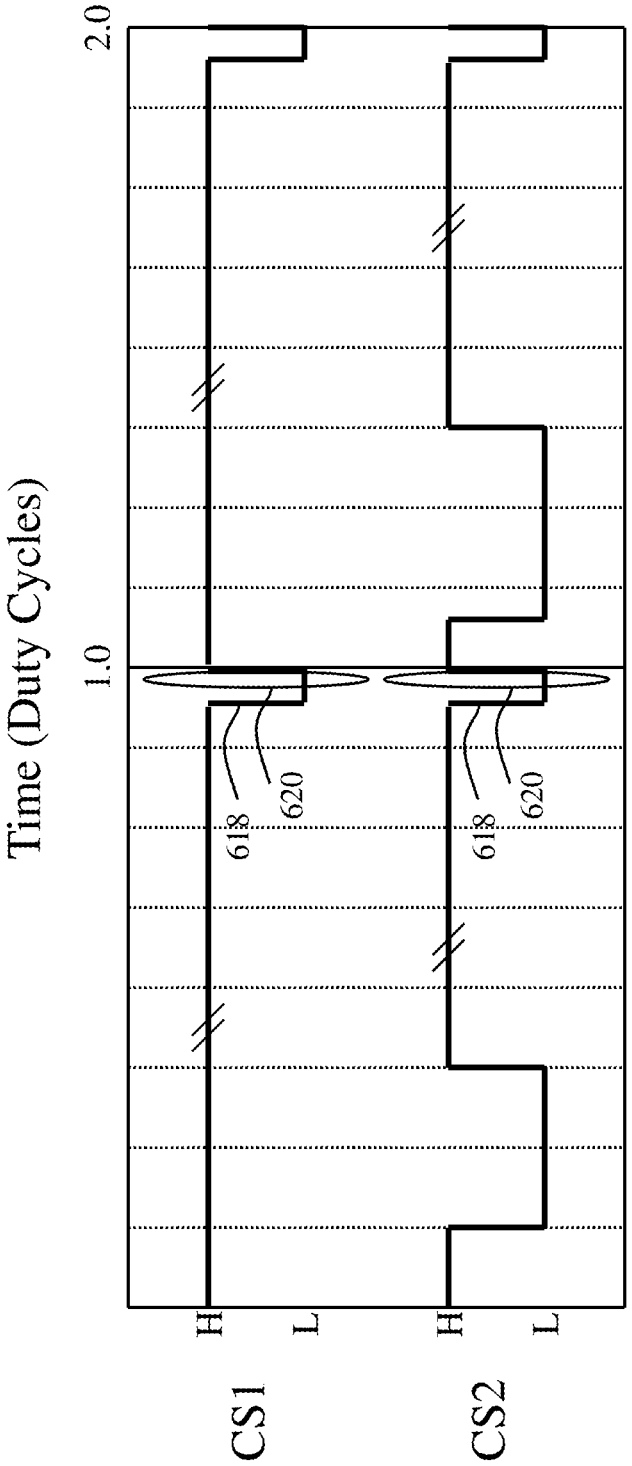

FIGURE 6D

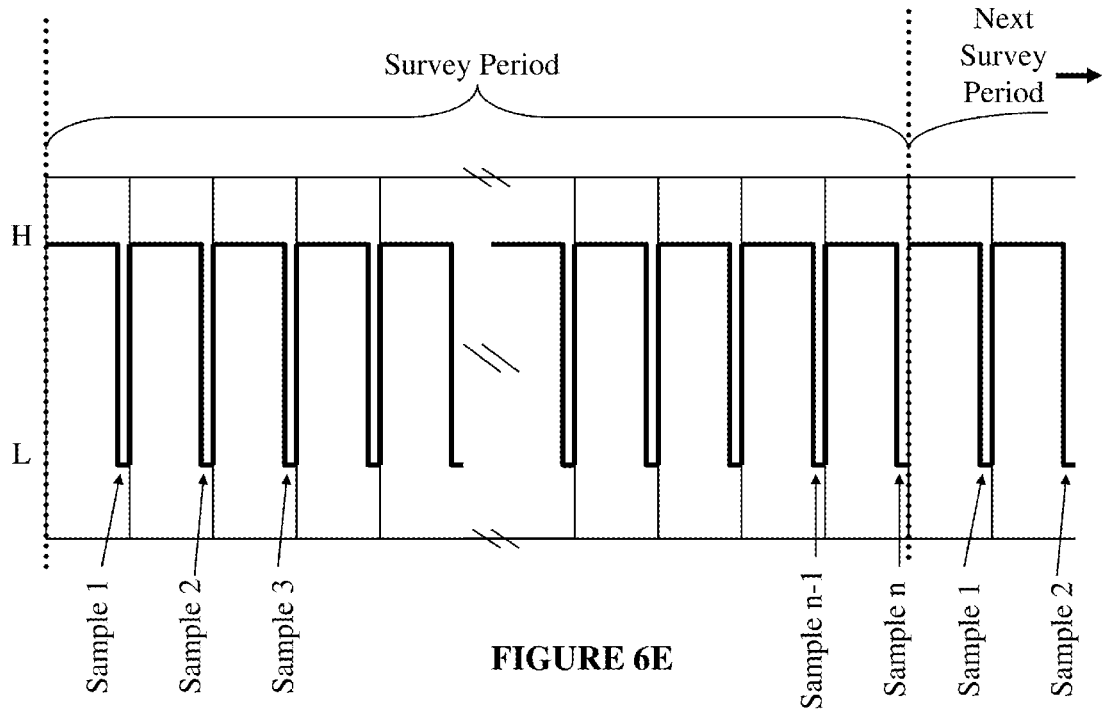
Survey Period
Next Survey Period
H
L
Sample 1
Sample 2
Sample 3
Sample n-1
Sample n
Sample 1
Sample 2

FIGURE 6E

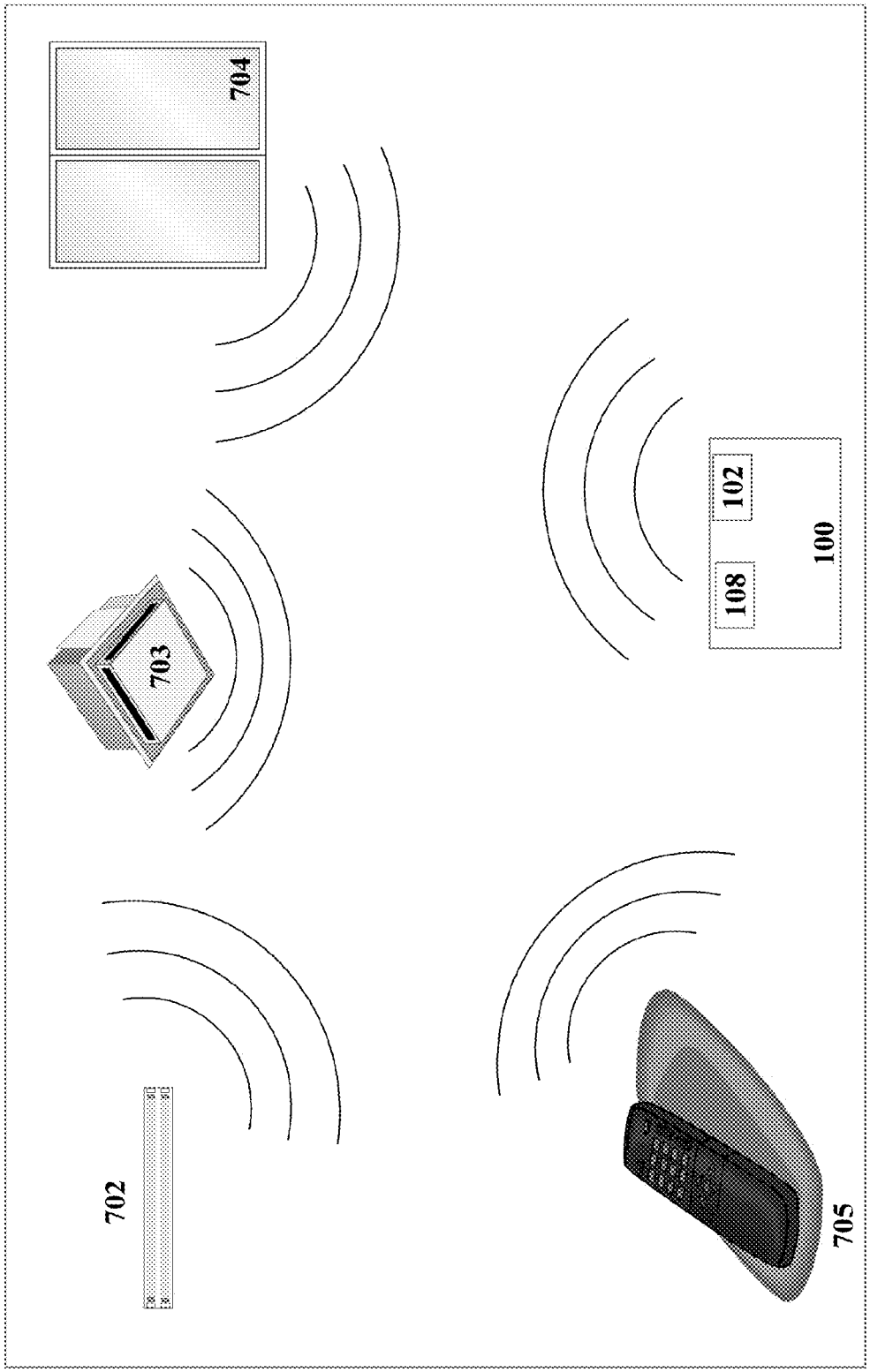

FIGURE 7

LIGHTING APPARATUS AND METHODS FOR CONTROLLING LIGHTING APPARATUS USING AMBIENT LIGHT LEVELS

CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation of and claims the benefit under 35 USC 120 of U.S. patent application Ser. No. 13/423,135 entitled "LIGHTING APPARATUS AND METHODS FOR CONTROLLING LIGHTING APPARATUS USING AMBIENT LIGHT LEVELS" by Briggs filed on Mar. 16, 2012 which claims the benefit under 35 USC 119(e) of U.S. Provisional Patent Application 61/453,542 filed on Mar. 16, 2011 and hereby incorporated by reference herein.

FIELD OF THE INVENTION

The invention relates generally to lighting systems and, more particularly, to lighting apparatus and methods for controlling lighting apparatus using ambient light levels.

BACKGROUND

Light Emitting Diodes (LEDs) are increasingly being adopted as general illumination lighting sources due to their high energy efficiency and long service life relative to traditional sources of light such as incandescent, fluorescent and halogen. Each generation of LEDs are providing improvements in energy efficiency and cost per lumen, thus allowing for lighting manufacturers to produce LED light fixtures at increasingly competitive prices. One differentiator for LEDs over the traditional sources of light is their ability to be controlled very precisely relative to other lighting technologies, with the ability to switch on and off in microseconds.

The intensity of the LEDs within LED lighting fixtures may be adjusted using Pulse Width Modulation (PWM) (i.e. changing the time that the LEDs are activated) or by modifying the current that flows through the LEDs. Some LED systems interoperate with independent light sensors that are operable to continuously detect the local light level. In some cases, the LED lighting fixture will have a desired light level (possibly full intensity or a particular dimmed level set by a user) and may adjust the intensity of the LEDs until the light level detected by the light sensor reaches this desired level. In this system, daylight that may be radiating through windows and/or light from other light sources can be used to reduce the required intensity of light from the LED lighting fixture (generally called "daylight harvesting"), hence reducing overall energy usage required to achieve the desired light level within a room. One problem with this type of daylight harvesting implementation is that it requires the independent light sensor which may be an expensive added component to the system. In this type of architecture, it would be difficult to implement the light sensor within the lighting fixture since the light from the lighting fixture would dominate the light detected by the light sensor.

In some implementations, such as the system disclosed within U.S. Patent Application No. 2010/0171442 by Draper et al., herein incorporated by reference, the lighting system integrates a light sensor into or proximate to the lighting fixture itself and attempts to directly detect ambient light levels (i.e. light coming from other light sources other than the lighting fixture itself) during times in which the LEDs are turned off or reduced in power. In these implementations, the controller may sense the ambient light during a time period of the LEDs in their duty cycle in which they are off and then can adjust the current to dim the light intensity in response to the sensed ambient light as it compares to target data. U.S. Patent Application No. 2010/0171429 by Garcia et al. discloses a similar LED system in which ambient light levels are detected during periods of time in which LEDs are turned off.

There are considerable problems with these integrated systems that include light sensors within LED light fixtures and adjust the intensity of the LEDs based upon ambient light levels sampled in very short time periods (ex. one millisecond) while the LEDs are turned off in a duty cycle. The reality of most environments is that the sources of ambient light are often not consistent in their level of light output and may be relatively unstable when sensed within such a limited time period. In particular, fluorescent and neon lights produce oscillation lighting which has dynamically changing light level outputs that may or may not be perceptible to the human eye. Further, other LED lighting fixtures in the same environment may operate using PWM signaling and have periods of time within each duty cycle in which the LEDs are activated and other periods of time in which the LEDs are deactivated. Yet further, video monitors and televisions that may operate within the environment of the LED lighting fixture may have significant changes of their light level outputs due to changes in the content being displayed in a particular moment of time. Also, use of an infrared remote in proximity to the light sensors may increase a sensed light level at the light sensors temporary. Even natural sources of light such as lightning can cause significant temporary changes in a sensed light level at the light sensors.

These inconsistent sources of ambient light would lead to very different light levels being sampled with each sample within the systems of Draper and Garcia. For instance, in any particular moment, the light level sensed at the light sensor may be significant due to the LEDs within another local LED lighting fixture being activated, the oscillation of a neon or fluorescent lighting fixture providing a high light level, an infrared remote being used, etc. The next moment, the light level sensed at the light sensor may be relatively low due to the LEDs within the other local LED lighting fixture being deactivated, the oscillation of the neon or fluorescent lighting fixture providing a low light level, the infrared remote not being used anymore, etc. These fluctuations in detected light levels may lead directly to large fluctuations in the intensity of the LED lighting fixture as the controller adjusts the intensity of the light fixture in direct response to each of these detected ambient light levels. These fluctuations can cause significant flicker issues within the LED lighting fixture that would likely be perceivable to the human eye and could disturb the user of the lighting fixture.

Against this background, there is a need for solutions that will mitigate at least one of the above problems, particularly allowing LED light fixtures to adjust intensity levels consistently and smoothly in response to ambient light levels.

SUMMARY OF THE INVENTION

According to a first broad aspect, the present invention is a lighting apparatus comprising: one or more light radiating devices operable to be activated and deactivated; a light detection apparatus operable to sense light levels local to the lighting apparatus; and a control apparatus. The control apparatus is operable to sample a light level using the light detection apparatus at a plurality of sampling times during which the light radiating devices are deactivated, the plurality of sampling times occurring over a survey time period. The control apparatus is further operable to generate an average of the

light levels sampled over the survey time period; and to adjust a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled over the survey time period.

According to a second broad aspect, the present invention is a method for adjusting a luminous intensity of a lighting apparatus. The lighting apparatus comprises one or more light radiating devices operable to be activated and deactivated. The method comprises: sampling a light level at a plurality of sampling times during which the light radiating devices are deactivated, the plurality of sampling times occurring over a survey time period; generating an average of the light levels sampled over the survey time period; and adjusting a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled over the survey time period.

According to a third broad aspect, the present invention is a computer-readable media containing a program element executable by a computing system to perform a method for adjusting a luminous intensity of a lighting apparatus. The lighting apparatus comprises one or more light radiating devices operable to be activated and deactivated. Said program element comprises program code for sampling a light level at a plurality of sampling times during which the light radiating devices are deactivated, the plurality of sampling times occurring over a survey time period; program code for generating an average of the light levels sampled over the survey time period; and program code for adjusting a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled over the survey time period.

These and other aspects of the invention will become apparent to those of ordinary skill in the art upon review of the following description of certain embodiments of the invention in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

A detailed description of embodiments of the invention is provided herein below, by way of example only, with reference to the accompanying drawings, in which:

FIGS. **1**A to **1**E are logical system diagrams of a lighting apparatus according to embodiments of the present invention;

FIGS. **2**A, **2**B and **2**C are flow charts depicting steps performed by a controller operating in an ambient light adjustment mode according to an embodiment of the present invention;

FIGS. **3**A, **3**B, **3**C and **3**D are circuit diagrams of a light detection apparatus according to embodiments of the present invention in which a phototransistor is utilized;

FIGS. **4**A, **4**B, **4**C and **4**D are circuit diagrams of a light detection apparatus according to embodiments of the present invention in which a photodiode is utilized;

FIGS. **5**A, **5**B, **5**C and **5**D are circuit diagrams of a light detection apparatus according to embodiments of the present invention in which a photoresistor is utilized;

FIGS. **6**A, **6**B, **6**C, **6**D and **6**E are example signal diagrams for control signals that may control a light engine of FIGS. **1**A to **1**E; and

FIG. **7** is a graphical illustration of light sources within an example room in which a lighting apparatus according to the present invention may be located.

It is to be expressly understood that the description and drawings are only for the purpose of illustration of certain embodiments of the invention and are an aid for understanding. They are not intended to be a definition of the limits of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

The present invention is directed to lighting apparatus and methods for controlling lighting apparatus using ambient light levels. Within various embodiments of the present invention, a controller within a lighting apparatus is used to activate and deactivate one or more light radiating devices. In a first stage, the controller uses a light detection apparatus to sample an ambient light level at a plurality of sampling times during which the light radiating devices are deactivated. The light level when the light radiating devices are deactivated is an indication of the ambient light levels within the surrounding area of the lighting apparatus. The sampling times occur in different duty cycles within a survey time period. In one example implementation, a sample is taken every 16^{th} duty cycle and 256 samples may be taken over a survey time period of ~4.1 seconds. The controller determines an average for the light levels sampled over the survey time period, thus generating an averaged ambient light level over the survey time period.

In a second stage, the controller adjusts an intensity of the light radiating devices based at least partially upon the averaged ambient light level. In some embodiments of the present invention, the controller generates a target light level using the averaged ambient light level over the survey time period and a desired light level. The desired light level may be determined internally to the controller or may be set by an external component such as a master controller, dimmer, sensor, remote control, building management system, etc. The target light level may be generated by calibrating the averaged ambient light level and proportionally reducing the desired light level by a ratio of the averaged ambient light level to a maximum possible light level. In another embodiment, the averaged ambient light level may be subtracted from the desired light level to generate the target light level. Over an adjustment time period, the controller may then incrementally adjust the intensity of the light radiating devices towards the target light level.

In one example implementation in which the controller uses PWM to control the intensity of the light radiating devices, the controller may continuously compare (ex. every duty cycle, every N duty cycles, at predetermined time intervals, randomly, etc.) a currently set light level for the light radiating devices to the target light level. If the currently set light level is not equal to the target light level, the controller can incrementally adjust the currently set light level for the light radiating devices to decrease the difference between the currently set light level and the target light level. In one case, there may be 65,536 intensity levels for the light radiating devices and the controller may adjust the currently set light level up or down 16 intensity levels each duty cycle if the currently set light level is not equal to the target light level. In this case, if the duty cycle is approximately 1 ms, it would take the controller ~4.1 seconds to adjust the intensity of the light radiating devices from the maximum intensity to the minimum intensity or vice versa as may be required.

Embodiments of the present invention are described below in which the light radiating devices comprise Light Emitting Diodes (LEDs). It should be understood that in some embodiments of the present invention, other light radiating devices could be utilized and the use of LEDs within the description is not meant to limit the scope of the present invention. Specifically, other light radiating devices that allow for suffi-

ciently quick activations/deactivations may be employed. Further, light radiating devices that allow for sufficiently fast adjustments in luminous intensity levels may also be employed.

FIG. **1**A is a logical system diagram of an LED lighting apparatus **100** according to one embodiment of the present invention. As depicted, the LED lighting apparatus **100** comprises a number of distinct components that together enable the lighting apparatus **100** to output light. The LED lighting apparatus **100** comprises a light engine **102** which comprises a circuit with LEDs that emit light when activated, the LEDs are one example of light radiating devices; a controller **104** that outputs control signals to the light engine **102** to control the LEDs; an AC/DC power supply **106** that receives AC power from the power grid (not shown) and provides DC power to the controller **104** and the light engine **102**; and a light detection apparatus **108** that can detect light levels local to the lighting apparatus **100**. Other elements not shown in FIG. **1**A but that may also be included within the lighting apparatus **100** include an optics element that diffuses the light output from the LEDs; a thermal element that removes heat generated by the LEDs in order to enable them to operate at an acceptable temperature; and an encasement that provides protective structure and artistic design to the lighting apparatus **100**. Further, external control components could be coupled to the lighting apparatus **100** such as dimmers, motion/occupancy sensors, DMX controllers, a master LED controller and/or a building management system.

The light engine **102** may take many shapes, sizes and form factors. It should be understood that although depicted as a single component in FIG. **1**A, the light engine **102** may comprise a plurality of components. Further, all or some of the elements within the light engine **102** may be integrated within another component such as the controller **104**, the thermal element (not shown) or even the encasement (not shown) or optics element (not shown).

The controller **104** in FIG. **1**A manages the activation of the LEDs within the light engine **102** as will be described in detail herein below and, therefore, controls the output luminous intensity and possibly light spectrum that is generated by the lighting apparatus **100**. In the architecture depicted in FIG. **1**A, the controller **104** receives a constant voltage rail or a constant current source and a reference ground from the AC/DC power supply **106**. The controller **104**, as will be described below in detail, is operable to sample light levels using the light detection apparatus **108** and may control aspects of the light output from the light engine **102** in response. The controller **104** may further access information stored within a local memory (not shown), internal software or firmware or external components to generate the control signals for the light engine **102**. In some embodiments of the present invention, each of the control signals transmitted by the controller **104** to the light engine **102** may comprise a pulse signal that may be in an active high state for a set time within a duty cycle.

As one skilled in the art would understand, the controller **104** can take a number of different forms including a microcontroller programmed with software, firmware, an ASIC, an FPGA, a microprocessor, logical hardware components or other components that can generate digital signals. In one particular embodiment, the controller comprises a microprocessor from Microchip Technologies Inc. of Chandler, Ariz., USA.

The AC/DC power supply **106** may comprise a large number of different power supply configurations depending upon the particular application. For instance, the AC/DC power supply **106** should be selected to match the power needs of the light engine **102** and the controller **104** and particularly to the LEDs within the light engine **102** which will utilize the majority of the power. In one example, a 24V/20 W power supply may be used in a light engine configuration that activates 7 LEDs in series at a time, each LED having a voltage drop of approximately 3.4V in this example. The light detection apparatus **108** may be implemented in many different manners in different embodiments as will be described in detail with reference to FIGS. **3**A to **3**D, **4**A to **4**D and **5**A to **5**D. The light detection apparatus **108** is operable to sense light levels local to the lighting apparatus **100** and enable the controller **104** to sample the light levels local to the lighting apparatus **100** at various times in operation. The light detection apparatus **108** may be optically isolated from the light engine **102** such that it does not directly sense light being transmitted by the LEDs within the light engine **102**, though in other embodiments, the light detection apparatus **108** may be integrated into the lighting apparatus **100** with little or no optical isolation from the light engine **102**.

It should be understood that the lighting apparatus **100** of FIG. **1**A is only a sample lighting architecture that could be used with the present invention and should not be used to limit the scope of the present invention. Large numbers of alternative lighting architectures are understood by one skilled in the art, a few of which are described with reference to FIGS. **1**B to **1**E. As depicted in FIG. **1**B, the light detection apparatus **108** may be integrated within the light engine **102**. The advantage of this architecture is that light detection apparatus **108** may detect ambient light local to the lighting apparatus **100** through the optics that the LEDs within the light engine **102** use to radiate light. As depicted in FIG. **1**C, the lighting apparatus **100** may comprise a plurality of light detection apparatus **108***a*, **108***b* integrated within the light engine **102** or another location within the lighting apparatus (not shown). The use of a plurality of light detection apparatus **108***a*, **108***b* may allow for a more complete sampling of the light level local to the lighting apparatus **100**. As depicted in FIG. **1**D, the light detection apparatus **108** may be integrated within the controller **104**.

This architecture allows for a reduced number of components to be implemented within the lighting apparatus **100** and reduces needs for cabling and likely reduces costs. As depicted in FIG. **1**E, the controller **104** and the light detection apparatus **108** may be integrated within the light engine **102**. In the case shown, the light engine **102** is a rectangular array with the controller **104** implemented in the center and the light detection apparatus **108** integrated within the controller **104**. The LEDs within the light engine **102** of FIG. **1**E may be implemented surrounding the controller **104** and may be sufficiently close to the controller **104** to avoid having a significant dark spot in the array.

FIG. **7** is a graphical illustration of light sources within an example room in which the lighting apparatus **100** may be located. In this graphical illustration, the lighting apparatus **100** is shown in a simplified form for clarity which only includes the light engine **102** and the light detection apparatus **108**. As depicted in FIG. **7**, along with the lighting apparatus **100** in this example room, there are additional sources of light, namely a light fixture **702**, shown as a fluorescent light tube; a light fixture **703**, shown as a troffer that may include one or more LED light engines that are controlled by PWM; a window **704** which may allow sunlight into the room during the daytime and light from street lights, etc. at night; and an infrared remote control **705** that may control a television or another electronic component in the room (ex. lighting apparatus **100**).

In embodiments of the present invention, the controller **104** (not shown in FIG. **7** for simplicity) samples the light level local to the lighting apparatus **100** using the light detection apparatus **108** at a plurality of sampling times within a survey time period, each of the sampling times occurring when the LEDs are deactivated. One can approximate the ambient light level sensed at the light detection apparatus **108** when the controller **104** controls the light engine **102** to deactivate the LEDs in the example of FIG. **7** as:

$$I_V(t_1)=I_{A1}+I_{A2}+I_{A3}+I_{A4}+I_N$$

where: $I_V(t_1)$ is the light level sensed at the light detection apparatus **108** at a time t_1; I_{A1}, I_{A2}, I_{A3} and I_{A4} are the light levels sensed at the light detection apparatus **108** due to direct light from the light fixture **702**, light fixture **703**, window **704** and infrared remote control **705** respectively; and; I_N is a level of noise sensed at the light detection apparatus **108**.

The controller **104** averages the sampled light levels across the plurality of sampling times (ex. averaging 256 sampled light levels taken over a survey time period of ~2.5 seconds). By taking a large number of samples and averaging the sampled light levels across a long period of time relative to the instability of many of the ambient light sources, the controller **104** can control the luminous intensity of the lighting apparatus **100** using a more appropriate approximation of the actual ambient light level compared to using instantaneous samples of the ambient light level as done in prior art systems. For instance, by using a large number of samples of the ambient light level, systematic fluctuations in the ambient light level caused by oscillations within neon or fluorescent lights (ex. light fixture **702**) or caused by the PWM of the LEDs within an LED light fixture (ex. light fixture **703**) can be averaged, similar to how the human eye would naturally average out the light from such light fixtures and see simply a constant light output. Further, the impact of any temporary fluctuations in the ambient light level caused by the use of an infrared remote (ex. remote **705**) or caused by lightning seen through a window (ex. window **704**), etc. would be mitigated by the averaging of the ambient light levels over the survey time period. Other inconsistent ambient light sources, such as video displays and televisions, would similarly have their light levels averaged, hence effectively contributing a light "noise" level to the average of the sampled light levels.

FIGS. **2**A, **2**B and **2**C are flow charts depicting steps performed by the controller **104** operating in an ambient light adjustment mode according to an embodiment of the present invention. In some embodiments of the present invention, the steps depicted in FIGS. **2**A, **2**B and **2**C describe distinct algorithms operating within the controller **104**, though in other embodiments, two or more of these algorithms may be integrated together or the steps of these algorithms could be divided into further algorithms. Further, it should be understood that these flow charts depict sample steps performed by the controller **104** in some embodiments of the present invention and other implementations of the present invention may modify one or more of these steps.

FIG. **2**A depicts steps performed by the controller **104** in determining an averaged ambient light level over a survey time period according to one embodiment of the present invention. As shown, the steps of FIG. **2**A are performed by the controller **104** upon initiation of an ambient light adjustment mode at step **202**.

Firstly, as shown at step **204**, the controller **104** samples a light level when the LEDs within the light engine **102** are deactivated (i.e. turned off) using the light detection apparatus **108**. The time in which the LEDs are deactivated may be a time in which the controller **104** forces the LEDs deactivated as will be described in detail with reference to FIG. **6**A or may be a time in which the LEDs are deactivated due to normal PWM signaling as will be described in detail with reference to FIG. **6**B. This sampled light level when the LEDs in the light engine **102** are deactivated is a representation of the instantaneous ambient light level local to the lighting apparatus **100** at that particular time. To ensure minimum impact of the light from the lighting apparatus **100** on the sampled light level, the controller **104** may delay sampling the ambient light level by a short period of time (ex. ~10 μs) to ensure that any residual excitation of the phototransistor (or other photo sensitive element used) from the light of the LEDs within the light engine **102** that was recently turned off is no longer present on the phototransistor; and to ensure that phosphor cool-down time of the LEDs within the light engine **102** has been effectively reached. In one implementation, the controller **104** inputs the sampled light level into a two byte register called SampleHigh:SampleLow (SH:SL).

Next, as shown at step **206**, the controller **104** adds the sampled light level to a Running Sample Register (RSR). In one implementation, the RSR comprises a three byte register called RunningSampleMega:RunningSampleHigh:RunningSampleLow (RSM:RSH:RSL) and the sampled light level as stored in SH:SL is added to the current value of the RSR. In this case, SL is added to RSL, any carry bits are added to RSH along with SH and RSM is incremented if there is an RSH carry bit.

Subsequently, at step **208**, the controller **104** increments a Sample Count Register (SCR) which in one implementation is a one byte register (i.e. 256 bit register). At step **210**, the controller **104** determines if the SCR is greater than a predetermined limit of samples that are to be taken within a single survey time period. In one implementation, the survey time period comprises 256 samples of the ambient light levels and therefore, when the one byte SCR resets to zero, the controller **104** determines that the SCR is greater than the limit. If the SCR has not exceeded the limit at step **210**, then the controller **104** returns to step **204** and takes an additional sample of the ambient light level when the LEDs within the light engine **102** are deactivated. In specific implementations, the controller **104** is operable to sample the light level every duty cycle, every X duty cycles (ex. every 16 duty cycles) or every predetermined time interval. In a specific example in which a) the controller ~104 samples the light level every 16^{th} duty cycle; b) the controller **104** operates at 1 kHz (i.e. a duty cycle is equal to ~1 ms); and c) the survey time period comprises 256 samples of the light level; the entire survey time period comprises ~4.1 seconds and the RSR will comprise the sum of 256 sampled light levels.

At step **212**, the controller **104** uses the RSR to set an Ambient Light Register (ALR), which is a register used to store an average of the light levels sampled within the previous survey time period. In one implementation, in which the RSR comprises the three byte RSM:RSH:RSL, to calculate the approximate average of the 256 sampled light levels, the controller **104** simply needs to drop the RSL byte. This operation effectively divides the RSR by 256 leaving the RSM:RSH bytes as the average of the sampled light levels. In this case, the controller **104** inserts the RSM:RSH bytes into the ALR at step **212**. Finally, at step **214**, the controller **104** resets the RSR and the SCR to zero and returns to step **204** to begin the subsequent survey time period.

The algorithm depicted in FIG. **2**A is one sample embodiment for the controller **104** to provide an averaged ambient light level to the ALR and to systematically update the ALR with a new averaged ambient light level every survey time period. In one implementation as discussed, the survey time

period may be ~4.1 seconds and therefore the ALR in that case would be updated every ~4.1 seconds.

FIG. **2**B depicts steps performed by the controller **104** in using the averaged ambient light level as stored in ALR and a desired light level known to the controller **104** to generate a target light level for the lighting apparatus **100**. The desired light level is a value (in one implementation, a two byte number from 1 to 65,536) that the controller **104** would have used to control the luminous intensity of the lighting apparatus **100** if the ambient light adjustment mode was not initiated. The desired light level may be calculated internally by the controller **104** (ex. based upon specific algorithms known to one skilled in the art) or may be received from an external component including, but not limited to, a dimmer, a motion/occupancy sensor, a master controller within another lighting apparatus, an infrared remote, a building management system, etc. In some embodiments, the desired light level is always the full "on" status in which all of the LEDs are fully activated and no dimming takes place (in one implementation such as this, the desired light level may be set to 65,636). As shown, the steps of FIG. **2**B are performed by the controller **104** upon initiation of an ambient light adjustment mode at step **202**.

At step **216**, in some implementations, the controller **104** may need to calibrate the averaged ambient light level within the ALR prior to performing operations with the desired light level since the ALR may not be scaled equivalently to the desired light level. The calibration depends upon the implementation of the light detection apparatus **108** and specifically resistors **304** and **314** within the various embodiments of the light detection apparatus **108** depicted in FIGS. **3**A-**3**D, **4**A-**4**D and **5**A-**5**D. In some cases, no calibration is required.

Next, at step **218**, the controller **104** performs operations to generate a target light level using the calibrated ALR and the desired light level. In one implementation, the controller **104** is operable to proportionally reduce the desired light level based upon the ratio of the averaged ambient light level to the maximum possible level (in some implementation, the maximum possible level being 65,536). To do this, in one case, the controller **104** is operable to complement the ALR (i.e. flip all bits from 1 to 0 or 0 to 1) and multiply the result of the complement of ALR by the desired light level. The result of the multiplication, after the least significant two bytes are dropped, comprises a representation of the desired light level reduced proportionally by the ratio of the averaged ambient light level to the maximum possible level. For example, if the averaged ambient light level was extremely high (close to the maximum), the complement would be very low and the resulting target light level would be very low as a proportion to the desired light level. One skilled in the art would understand there are alternative manners to generate a target light level using the desired light level and the averaged ambient light level. For instance, in one alternative, the controller **104** may subtract the averaged ambient light level from the desired light level in order to generate the target light level. Other mathematical operations should be understood and should not limit the scope of the present invention.

At step **220**, the controller **104** waits for a new ALR to be set, which may occur each survey time period as per described with reference to the algorithm of FIG. **2**A. If a new desired light level is received and/or calculated at the controller **104**, the steps **218** and **220** may also need to be repeated.

The algorithm depicted in FIG. **2**B is one sample embodiment for the controller **104** to generate a target light level and to systematically update the target light level with a new target light level. In one implementation as discussed, the survey time period may be ~4.1 seconds and therefore the target light level in that case may be updated every ~41 seconds.

FIG. **2**C depicts steps performed by the controller **104** in using the target light level as calculated in the algorithm of FIG. **2**B to adjust the light intensity of the lighting apparatus **100**. As shown, the steps of FIG. **2**C are performed by the controller **104** upon initiation of an ambient light adjustment mode at step **202**.

As shown in step **224**, the controller **104** compares a currently set light level for the lighting apparatus **100** to the target light level. The currently set light level may take many forms depending upon the implementation. In one implementation, the currently set light level comprises a two byte register that may be set to any one of 65,536 levels. The currently set light level may be used by the controller **104** to set PWM dimming of the LEDs within the light engine **102**, adjust the current flowing through the LEDs within the light engine **102** or otherwise adjust the intensity of the LEDs within the light engine **102** to a plurality of intensity levels. If at step **226**, the controller determines that the currently set light level is equal to the target light level, then the controller **104** simply continues to monitor the target light level as it may change due to the algorithm described in detail with reference to FIG. **2**B. If the currently set light level does not equal the target light level at step **226**, the controller **104** adjusts the currently set light level to bring it closer to the target light level at step **228**. In some embodiments, the controller **104** may adjust the currently set light level over numerous different incremental changes to reduce the difference between the currently set light level and the target light level within an adjustment time period. In one implementation, the controller **104** performs the algorithm of FIG. **2**C each duty cycle and, if the currently set light level does not equal the target light level, the controller **104** adjusts the currently set light level by X levels every duty cycle until the currently set light level is equal to the target light level. In one case, in which X is equal to 16, a duty cycle comprises ~1 ms and there are 65,536 levels within the currently set light level, the adjustment time period for the controller **104** to move the currently set light level from its minimum to its maximum levels (or vice versa) in response to a target light level may be up to ~4 seconds.

The algorithm depicted in FIG. **2**C is one sample embodiment for the controller **104** to adjust a currently set light level in response to a target light level over an adjustment time period. This adjustment time period allows for smooth transitions of the luminous intensity of the lighting apparatus **100** to be implemented as the average ambient light level, and therefore the target light level, changes.

The algorithms of FIGS. **2**A, **2**B and **2**C provide a two stage process for adjusting the luminous intensity of the lighting apparatus **100** in response to ambient light levels local to the lighting apparatus **100**. In the first stage as described in detail with reference to FIG. **2**A, the controller **104** generates an averaged ambient light output over the survey time period. In the second stage as described in detail with reference to FIGS. **2**B and **2**C, the controller **104** generates a target light level from the previously generated averaged ambient light level and adjusts the currently set light level (and therefore the luminous intensity of the lighting apparatus **100**) to the target light level over the adjustment time period. The combination of the averaging of the ambient light levels over the survey time period and the smooth adjusting of the currently set light level towards the target light level over the adjustment time period removes any significant fluctuations in luminous intensity from occurring within the lighting apparatus **100** and mitigates problems that may occur due to inconsistent ambient light sources.

There is a probability, although relatively low, in which the controller **104** may perform the sampling of ambient light levels synchronized with an ambient light source's changes in luminous intensity. For example, another LED lighting apparatus may be proximate to the lighting apparatus **100** and may operate a PWM dimming at the same frequency as the lighting apparatus **100**. In this case, if synchronized, the samples of the ambient light levels may always be performed during a time that the other LED lighting apparatus has its LEDs activated in its duty cycle or during a time that the other LED lighting apparatus has its LEDs deactivated in its duty cycle. In this case, the averaged ambient light level will not depict the true average luminous intensity of the other LED lighting apparatus across its whole duty cycle. This problem could also occur with other ambient light sources that may operate on a similar frequency to the lighting apparatus **100**. In some embodiments, to mitigate this problem, the controller **104** may adjust the time within the duty cycle in which the samples of the ambient light levels are performed. In one implementation, the time within the duty cycle in which the controller **104** samples the ambient light level may be randomized or set to change in a systematic manner. In another alternative, the clock of the controller **104** may be adjusted either systematically or randomly to ensure that any synchronization with other LED lighting apparatus would only be temporary. In other embodiments, the controllers within LED lighting apparatus that will be local to each other may be configured not to synchronize in another manner. Further, this problem may be reduced if the other LED lighting apparatus uses power conditioning PWM in which each channel of LEDs is activated and deactivated at different times within the duty cycle to reduce the strain on the power supply **106**. Power conditioning is described in U.S. patent application Ser. No. 12/624,414 by Briggs, entitled "METHOD, APPARATUS AND COMPUTER-READABLE MEDIA FOR CONTROLLING LIGHTING DEVICES", herein incorporated by reference.

The design of the light detection apparatus **108** may be done in many different manners. FIGS. **3**A to **3**D, **4**A to **4**D and **5**A to **5**D illustrate twelve various implementations for the light detection apparatus **108**, though it should be understood that numerous other designs are possible that could allow the controller **104** to sample a light level local to the lighting apparatus **100**. The design of the light detection apparatus **108** should not limit the scope of the present invention.

FIGS. **3**A, **3**B, **3**C and **3**D are circuit diagrams of the light detection apparatus **108** according to specific embodiments of the present invention in which a phototransistor **302** is utilized. As shown in FIG. **3**A, a light detection apparatus $\mathbf{108}_A$ comprises a phototransistor **302** coupled between a reference ground and a node N**1** while a resistor **304** with a value of R**1** is coupled between a supply voltage V_{DD} and the node N**1**. The node N**1** is further coupled to the controller **104** via an isolation resistor **306** with a value of R**2**. The phototransistor **302** has a dynamic resistance R_{CE} across its collector/emitter that is high if no light is detected (ex. 1 MΩ in one example) and goes lower as the phototransistor detects light (ex. 1 kΩ in intense light in one example). The phototransistor **302** has a relatively stable capacitance C_{CE} across its collector/emitter. The voltage V_1 at node N**1** is determined based on the voltage divider between resistor **304** and the resistance of the phototransistor **302**: $V_1=R_{CE}/(R1+R_{CE})\times V_{DD}$.

In some embodiments of the present invention, the resistance R**1** is selected to be small (ex. 500 in one example) in order to ensure a relatively fast response (for example ~10 μs) when the phototransistor **302** senses a change in light level. With a small value for resistance R**1**, the voltage V_1 is very close to the supply voltage V_{DD} and adjusts only slightly based upon the change of resistance across the phototransistor **302** as light is sensed. For example, in one implementation, the voltage V_1 may range from ~$0.999\times V_{DD}$ to ~$0.990\times V_{DD}$. In the embodiment of FIG. **3**A, the controller **104** comprises an analog to digital convertor (ADC) which is coupled to the node N**1** through the isolation resistor **306** and can convert a voltage at its connection to the light detection apparatus $\mathbf{108}_A$ to a digital value for the controller **104** to use as a light level sample. The voltage on either side of the isolation resistor **306** (which may be 1 kΩ in one example) is relatively constant due to the very low current so the sampled voltage is effectively the voltage V_1 on node N**1**.

The ADC within the controller **104** can be set to detect a range of voltages by setting an input for a reference voltage V_{ref} on the controller **104**. In one embodiment, the controller **104** uses the same supply voltage V_{DD} as the light detection apparatus $\mathbf{108}_A$ which may be 3V and the reference voltage V_{ref} is set at ~2.7V. This would provide a range of 0.3V (2.7V to 3V) for the ADC to detect voltages. In one example implementation, the ADC has a range of 1024 digital outputs depending linearly on the voltage that is converted. Therefore, with a range of 0.3V, the ADC would provide a unique digital output for each 0.29 mV change in the voltage. It should be understood that a different range of voltages could be utilized and/or a different level of digital outputs could be used. The smaller the range of voltages that is used and the larger number of digital outputs from the ADC, the more defined results that can be achieved for the voltage range of interest. For example, if it is known that the voltage V_1 will range between ~$0.999\times V_{DD}$ to ~$0.990\times V_{DD}$ and V_{DD} is 3V, then a V_{ref} of 2.95V could be utilized to provide a smaller range of voltages and to detect a more subtle change in voltage. One skilled in the art would understand that there are a large number of manners to implement a similar ADC. FIG. **3**B illustrates a modified light detection apparatus $\mathbf{108}_B$ which is similar to the light detection apparatus $\mathbf{108}_A$ of FIG. **3**A with like components having the same reference number. As shown, the light detection apparatus $\mathbf{108}_E$ further comprises an external ADC **308**. In this implementation, the controller **104** is not required to have an ADC and the output of the ADC **308** is a digital input to the controller **104**. The function of the light detection apparatus $\mathbf{108}_E$ is otherwise identical to that of the light detection apparatus $\mathbf{108}_A$ of FIG. **3**A.

FIG. **3**C illustrates a further modified light detection apparatus $\mathbf{108}_C$ which is similar to the light detection apparatus $\mathbf{108}_A$ of FIG. **3**A with like components having the same reference number. As shown, the light detection apparatus $\mathbf{108}_C$ comprises a phototransistor **312** coupled between the supply voltage V_{DD} and the node N**1** while a resistor **314** with a value of R**3** is coupled between a reference ground and the node N**1**. The voltage V_1 at node N**1** is determined based on the voltage divider between resistor **314** and the resistance of the phototransistor **312**: $V_1=R3/(R3+R_{CE})\times V_{DD}$.

In some embodiments of the present invention, the resistance R**3** is selected to be small (ex. 500 in one example) in order to ensure a relatively fast response (for example ~10 μs) when the phototransistor **312** senses a change in light level. With a small value for resistance R**3**, the voltage V_1 is very close to the reference ground and adjusts only slightly based upon the change of resistance across the phototransistor **312** as light is sensed. For example, in one implementation, the voltage V_1 may range from ~0.001V to ~0.010V. In the embodiment of FIG. **3**C, the controller **104** comprises an ADC similar to the controller **104** of FIG. **3**A. In this case, the ADC within the controller **104** can be set to detect a range of voltages by setting an input for a reference voltage V_{ref} on the

controller **104**. In one embodiment, the controller **104** uses the same reference ground as the light detection apparatus $\mathbf{108}_C$ and the reference voltage V_{ref} is set at ~0.3V. This would provide a range of 0.3V (0V to 0.3V) for the ADC to detect voltages. It should be understood that modifications or changes could also be implemented similar to the light detection apparatus $\mathbf{108}_A$ and controller **104** of FIG. **3**A. FIG. **3**D illustrates a modified light detection apparatus $\mathbf{108}_D$ which is similar to the light detection apparatus $\mathbf{108}_C$ of FIG. **3**C with like components having the same reference number. As shown, the light detection apparatus $\mathbf{108}_D$ further comprises the external ADC **308** similar to that depicted in FIG. **3**B. In this implementation, the controller **104** is not required to have an ADC and the output of the ADC **308** is a digital input to the controller **104**. The function of the light detection apparatus $\mathbf{108}_D$ is otherwise identical to that of the light detection apparatus $\mathbf{108}_C$ of FIG. **3**C.

FIGS. **4**A, **4**B, **4**C and **4**D are circuit diagrams of the light detection apparatus **108** according to alternative embodiments of the present invention in which a photodiode **402** is utilized. Each of FIGS. **4**A, **4**B, **4**C and **4**D illustrate a different implementation of a light detection apparatus $\mathbf{108}_E$, $\mathbf{108}_F$, $\mathbf{108}_G$, $\mathbf{108}_H$ respectively which are similar to the light detection apparatus $\mathbf{108}_A$, $\mathbf{108}_B$, $\mathbf{108}_C$, $\mathbf{108}_D$ respectively of FIGS. **3**A, **3**B, **3**C, **3**D with like components having the same reference number. Each of the light detection apparatus $\mathbf{108}_E$, $\mathbf{108}_F$, $\mathbf{108}_G$, $\mathbf{108}_H$ comprise a photodiode **402** in place of the phototransistor **302** of FIGS. **3**A, **3**B, **3**C, **3**D. The current flow through the photodiode **402** is linearly proportional to the light level that is sensed at the photodiode **402**. If no light is sensed at the photodiode **402**, no current flows through the photodiode **402**. For the implementations of FIGS. **4**A and **4**B, no light would result in the voltage V_1 at the node **N1** to be close to the supply voltage V_{DD}. For the implementations of FIGS. **4**C and **4**D, no light would result in the voltage V_1 at the node **N1** to be close to the reference ground. Current flowing through the photodiode **402** increases as light is sensed at the photodiode **402**. For the implementation of FIGS. **4**A and **4**B, this increased light would result in the voltage V_1 at the node **N1** to decrease from the supply voltage V_{DD}. For the implementation of FIGS. **4**C and **4**D, this increased light would result in the voltage V_1 at the node **N1** to increase from the reference ground. In specific implementations, the photodiode **402** is reverse biased to force it into photo conductive mode in order to allow for fast response times when light levels change, though photo conductive mode also increases the noise level. An ADC within the controller **104** of FIGS. **4**A and **4**C and the ADC **308** of FIGS. **4**B and **4**D can operate similar to as described with reference to FIGS. **3**A, **3**B, **3**C, **3**D and convert the voltage V_1 to a digital value that the controller **104** can use as a sampled light level.

FIGS. **5**A, **5**B, **5**C and **5**D are circuit diagrams of a light detection apparatus according to embodiments of the present invention in which a photoresistor **502** is utilized. Each of FIGS. **5**A, **5**B, **5**C and **5**D illustrate a different implementation of a light detection apparatus $\mathbf{108}_I$, $\mathbf{108}_J$, $\mathbf{108}_K$, $\mathbf{108}_L$ respectively which are similar to the light detection apparatus $\mathbf{108}_A$, $\mathbf{108}_B$, $\mathbf{108}_C$, $\mathbf{108}_D$ respectively of FIGS. **3**A, **3**B, **3**C, **3**D with like components having the same reference number. Each of the light detection apparatus $\mathbf{108}_I$, $\mathbf{108}_J$, $\mathbf{108}_K$, $\mathbf{108}_L$ comprise a photoresistor **502** in place of the phototransistor **302** of FIGS. **3**A, **3**B, **3**C, **3**D. The resistance of the photoresistor **502** is relative to the light level that is sensed at the photoresistor **502**. If no light is sensed at the photoresistor **502**, the photoresistor **502** has a very high resistance. For the implementations of FIGS. **5**A and **5**B, no light would result in the voltage V_1 at the node **N1** to be close to the supply voltage V_{DD}. For the implementations of FIGS. **5**C and **5**D, no light would result in the voltage V_1 at the node **N1** to be close to the reference ground. Resistance of the photoresistor **502** decreases as light is sensed at the photoresistor **502**. For the implementation of FIGS. **5**A and **5**B, this increased light would result in the voltage V_1 at the node **N1** to decrease from the supply voltage V_{DD}. For the implementation of FIGS. **5**C and **5**D, this increased light would result in the voltage V_1 at the node **N1** to increase from the reference ground. An ADC within the controller **104** of FIGS. **5**A and **5**C and the ADC **308** of FIGS. **5**B and **5**D can operate similar to as described with reference to FIGS. **3**A, **3**B, **3**C, **3**D and convert the voltage V_1 to a digital value that the controller **104** can use as a sampled light level. The photoresistor **502** has a relatively slow response time to light level changes compared to the phototransistor **302** of FIGS. **3**A, **3**B, **3**C, **3**D and the photodiode **402** in photo conductive mode of FIGS. **4**A, **4**B, **4**C, **4**D. This slow response time may make a photoresistor **502** unworkable in some implementations, such as embodiments in which light levels are sampled during time periods of a fast duty cycle in which LEDs are activated and deactivated such that the changes are not perceptible to the human eye.

In some embodiments of the present invention, the controller **104** controls the activation and deactivation of the light engine **102** within a duty cycle using a PWM control signal. FIGS. **6**A, **6**B, **6**C and **6**D are example signal diagrams for control signals that may control the light engine **102**. In the examples of FIGS. **6**A and **6**B, the control signal (CS) is activating and deactivating all of the LEDs on the light engine **102** with a single CS. In the examples of FIGS. **6**C and **6**D, there are two control signals, CS**1** and CS**2** which each control at least a portion of the LEDs in the light engine **102**. In the depicted embodiments, the controller **104** is controlling the light engine **102** to ensure that the controller **104** may conduct a sample of light output with the LEDs in the light engine **102** deactivated.

In one implementation in which there are 256 slots within a duty cycle, each slot comprising ~10 μs duration, the controller **104** includes additional slots of similar duration allocated to perform the sample of the light level described herein. During one or more of the additional slots, the controller **104** forces all LEDs within the light engine **102** to be deactivated (the "off" state), so that the ambient light only is detected when the controller **104** samples the light level using the light detection apparatus **108**. This forced deactivation can also be used in implementations in which the controller **104** controls the current level flowing through the LEDs of the light engine **102** in order to dim the luminous intensity of the lighting apparatus instead of using PWM signaling.

FIG. **6**A depicts an example signal diagram for control signal CS that may control the light engine **102**. In this example, the light engine **102** is to be set to 100% intensity over a 256 slot duty cycle followed by a forced deactivation **602** to allow the controller **104** to conduct sampling of the ambient light level with the light engine **102** deactivated. The control signal CS could also be used in the case that the controller **104** controls the current level flowing through the LEDs of the light engine **102** in order to adjust the luminous intensity of the lighting apparatus and only deactivates the LEDs during times in which a sampling of the ambient light level is desired. As shown, the control signal CS is at a high level for all of the slots (256 in this case) of the duty cycle up to a forced deactivation **602** of two slots. In other implementations, the forced deactivation **602** may be shorter or longer than two slots, depending upon design. In the implementation of FIG. **6**A, the controller conducts a sample of the ambient

light level **604** when the light engine **102** has been forced deactivated for one time slot to ensure the light level is consistent over the sample periods (ex. ~10 μs). One benefit of adding a forced deactivation at the end of a duty cycle is that the sampling of light levels becomes independent of the normal control of the light engine **102** for such functions as dimming, color control and/or color temperature control.

FIG. **6**E depicts a signal diagram which illustrates the signal diagram of FIG. **6**A but expanded out to a full survey time period. As shown, there are n sample times within the survey time period of FIG. **6**E. In one implementation, n may comprise 256 and the sample times may occur at the end of the duty cycle (as per FIG. **6**A) every 16^{th} duty cycle. In other implementations, other numbers of sample times could be within the survey time period and the samples could occur more or less than every 16^{th} duty cycle. In the case that controller **104** controls the current level flowing through the LEDs of the light engine **102** in order to adjust the luminous intensity of the lighting apparatus and only deactivates the LEDs during times in which a sampling of the ambient light level is desired, the survey time period could be divided by time segments and a forced deactivation of the LEDs and subsequent sampling of the ambient light level could occur each time segment.

In an alternative implementation, the controller **104** can conduct the sampling of an ambient light level during a period within the duty cycle in which the light engine **102** would already be deactivated due to normal control of the light engine **102** for such functions as dimming, color control and/or color temperature control. In this case, the controller **104** conducts the samples at times that coincide with the deactivation of the LEDs within the light engine **102**. FIG. **6**B depicts a signal diagram for control signal CS that may control the light engine **102**. In this case, for dimming purposes, the control signal CS is high and therefore the light engine is activated for a set number of slots up to time **608** and then low and therefore the light engine is deactivated for a set number of slots up to the end of the duty cycle. The controller **104** may conduct the sample of the ambient light level during any slot after time **608** in which the light engine **102** is deactivated. Shown in FIG. **6**B, the controller **104** may conduct the sample of the ambient light level at the end of the duty cycle (shown as sample **610**) or may conduct the sample of the ambient light level at another time during which the light engine **102** is deactivated (shown as sample **611**).

In some embodiments, the light engine **102** may comprise a plurality of sets of LEDs that are independently controlled by a plurality of control signals. In these cases, the controller **104** may conduct the sample of the ambient light level while coordinating with both of the control signals to ensure all of the LEDs within the light engine **102** are deactivated. FIG. **6**C depicts a signal diagram for first and second control signals CS**1**, CS**2** with which the controller **104** has coordinated samples of the first and second light levels. As shown, the first control signal CS**1** is at a high state for all but the final two slots of the duty cycle (an intensity of 99.2% if the duty cycle has 256 slots) while the second control signal is at a high state for all but the final twelve slots of the duty cycle (an intensity of 95.3%). In this example, the controller **104** conducts a sample of the ambient light level **614** in the final slot of the duty cycle during which both the first and second control signals CS**1**, CS**2** have deactivated (turned "off") their respective portion of the light engine **102**.

FIG. **6**D depicts a signal diagram for first and second control signals CS**1**, CS**2** with which the controller **104** has added a forced deactivation **618** at the end of the duty cycle. In this example, both the first and second control signals CS**1**, CS**2** control their respective portions of the LEDs within the light engine **102** as normal and have additional time slots (ex. two slots in FIG. **6**D) added at the end of the normal duty cycle (ex. 256 slots in one implementation). In this example, the controller **104** conducts a sample of the ambient light level **620** during the second slot of the forced deactivation **618** similar to the implementation of FIG. **6**A.

Various implementations of the present invention described herein have varying advantages. For instance, the very limited time (as little as 20 μs in some embodiments) for the controller **104** to conduct the samples of the ambient light level during some embodiments allows for the determination of an averaged ambient light level without causing flicker that is perceptible to the human eye. Further, the averaging of a plurality of sampled light levels allows the impact of any fluctuations in ambient light sources to be reduced in determining the target light level and therefore in the adjustment of the luminous intensity of the lighting apparatus **100**. Both the survey time period for averaging sampled light levels and the adjustment time period for incrementally adjusting the currently set light level to the target light level allows the lighting apparatus **100** to not over-react to ambient light changes and to not be affected significantly by instantaneous ambient issues. This eliminates the flicker that may otherwise be caused by ambient light sensors that react directly to instantaneous ambient light

Although various embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art that numerous modifications and variations can be made without departing from the scope of the invention, which is defined in the appended claims.

What is claimed is:

1. A control apparatus operable to control one or more light radiating devices operable to be activated and deactivated; wherein the control apparatus is operable:

to sample light levels at a plurality of times during which the light radiating devices are deactivated;

to generate an average of the light levels sampled; and

to adjust a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled.

2. A control apparatus according to claim **1**, wherein, to sample light levels, the control apparatus is operable to sample light levels at N respective times during which the light radiating devices are deactivated; wherein each of the N times occurs when the light radiating devices are deactivated within a different duty cycle.

3. A control apparatus according to claim **2**, wherein a first one of the N times occurs at a first time interval within a first duty cycle and a second one of the N times occurs at a second time interval within a second duty cycle, the first and second time intervals being different time intervals within their respective duty cycles.

4. A control apparatus according to claim **2**, wherein each of the N times occurs at a predetermined time within their respective duty cycles.

5. A control apparatus according to claim **4**, wherein the predetermined time intervals for at least two of the N times being different times within their respective duty cycles relative to each other.

6. A control apparatus according to claim **2**, wherein each of the N times occurs at a random time within their respective duty cycle.

7. A control apparatus according to claim **2**, wherein the control apparatus is operable to increment a sampling counter each time the control apparatus samples one of the N light

levels; and to generate the average of the light levels and reset the sampling counter once the sampling counter reaches N.

8. A control apparatus according to claim **1**, wherein, to generate an average of the light levels sampled, the control apparatus is operable to sum the light levels sampled within a registry and remove at least one least significant byte from the registry.

9. A control apparatus according to claim **1**, wherein, to adjust a luminous intensity for the light radiating devices, the control apparatus is operable to generate a target light level using the average of the light levels and a desired light level.

10. A control apparatus according to claim **9**, wherein, to generate a target light level, the control apparatus is operable to proportionally reduce the desired light level by a ratio between the average of the light levels and a maximum possible light level.

11. A control apparatus according to claim **10**, wherein, to proportionally reduce the desired light level by a ratio between the average of the light levels and a maximum possible light level, the control apparatus is operable to complement the average of the light levels and multiply the complement by the desired light level.

12. A control apparatus according to claim **9**, wherein, to generate a target light level, the control apparatus is operable to subtract the average of the light levels sampled from the desired light level.

13. A control apparatus according to claim **9**, wherein, to adjust a luminous intensity for the light radiating devices, the control apparatus is further operable to compare a currently set light level for the light radiating devices to the target light level; and, if the currently set light level is not equal to the target light level, to incrementally adjust the currently set light level for the light radiating devices to decrease the difference between the currently set light level and the target light level.

14. A control apparatus according to claim **13**, wherein the control apparatus is operable to incrementally adjust the currently set light level for the light radiating devices to decrease the difference between the currently set light level and the target light level at least once each duty cycle.

15. A control apparatus according to claim **13**, wherein the control apparatus is operable to incrementally adjust the currently set light level for the light radiating devices to decrease the difference between the currently set light level and the target light level a plurality of times during an adjustment time period until the currently set light level equals the target light level, the adjustment time period comprising a plurality of duty cycles.

16. A control apparatus according to claim **9**, wherein the control apparatus is operable to receive the desired light level from at least one of a master controller, a dimmer, a sensor, a remote control and a building management system.

17. A control apparatus according to claim **1**, wherein, to adjust a luminous intensity for the light radiating devices, the control apparatus is operable to adjust an activation time for the light radiating devices to be activated within a duty cycle based at least partially upon the average of the light levels.

18. A control apparatus according to claim **1**, wherein, to adjust a luminous intensity for the light radiating devices, the control apparatus is operable to adjust current level flowing through the light radiating devices based at least partially upon the average of the light levels.

19. A lighting apparatus comprising:

one or more light radiating devices operable to be activated and deactivated;

a light detection apparatus operable to sense light levels local to the lighting apparatus; and

a control apparatus operable to sample a light level using the light detection apparatus at a plurality of times during which the light radiating devices are deactivated; to generate an average of the light levels sampled; and to adjust a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled.

20. A method for adjusting a luminous intensity of one or more light radiating devices operable to be activated and deactivated, the method comprising:

sampling a light level at a plurality of times during which the light radiating devices are deactivated;

generating an average of the light levels sampled; and

adjusting a luminous intensity for the light radiating devices based at least partially upon the average of the light levels sampled.

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